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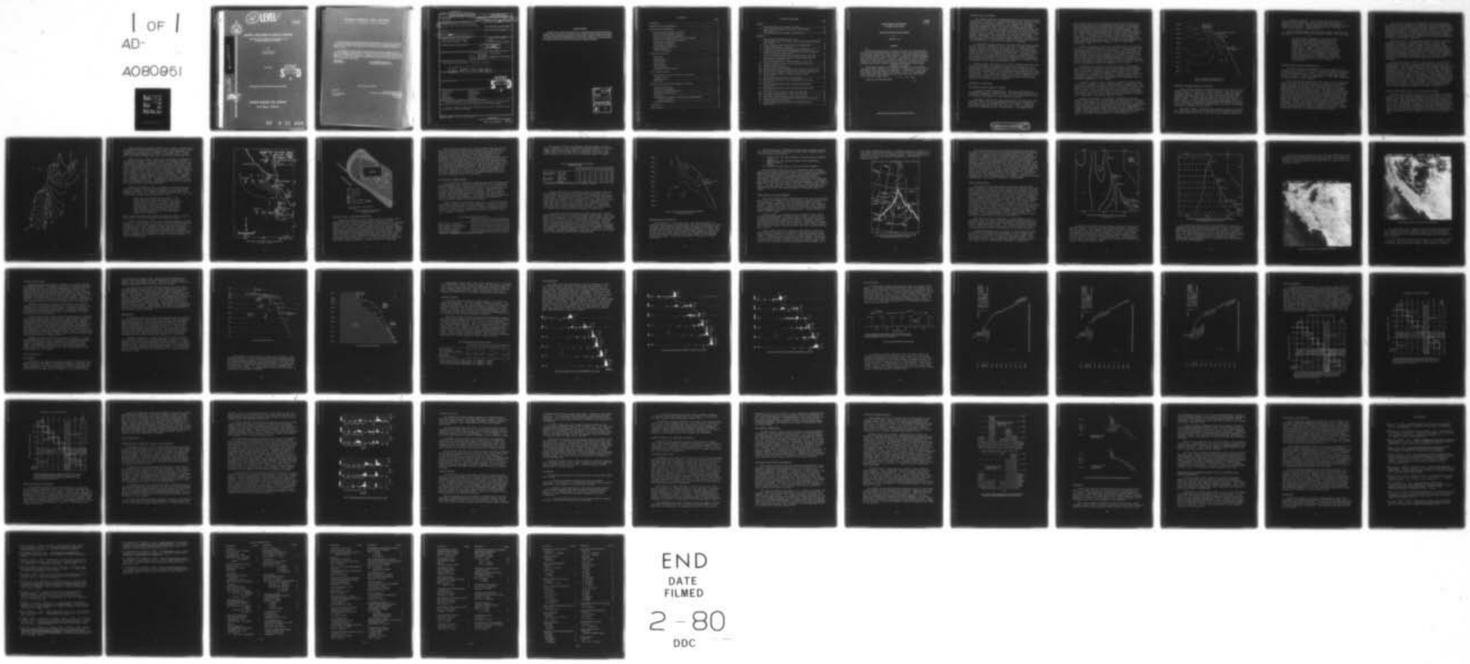

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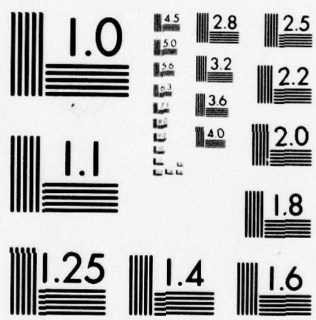

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DIURNAL VARIATIONS OF COASTAL STRATUS

(PREPARED IN PART UNDER NAVAIRSYSCOM AIR TASK
A370-370G/076B/9F52-551-792 (NEPRF))

by

Thomas Frederick Lee
Geophysics Division

June, 1979

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PACIFIC MISSILE TEST CENTER
Point Mugu, California

PACIFIC MISSILE TEST CENTER

AN ACTIVITY OF THE NAVAL AIR SYSTEMS COMMAND

This report is based on Mr. Thomas F. Lee's Masters Thesis submitted to and approved by the California State University, Northridge in June 1979 for the degree of Master of Arts in Geography (Climatology). The thesis effort is in turn based on work begun by Mr. Lee while employed in the Geophysics Division, Pacific Missile Test Center.

Dr. R. Gohstand, Dr. G-Y. Lin, and Dr. A. Court, California State University, Northridge approved the thesis; Mr. J. Rosenthal, Task Manager; Mr. D. A. Lea, Associate Geophysics Officer; CDR J. Tupaz, Geophysics Officer; Mr. R. C. Diehl, Project Manager; Dr. T. C. Lockhart, Associate Head, Range Operations; and Mr. J. F. Denlan, Acting Associate Director, Range Directorate, Pacific Missile Test Center, Point Mugu, California, have reviewed this document for publication.

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Technical Director

F. H. BAUGHMAN, RADM, USN
Commander, Pacific Missile Test Center

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Diurnal dissipation of stratus over and off the southern California and Baja California coasts during July, measured by GOES Visual Imagery.

Morning, Midday, and Afternoon variances are utilized to establish daily fluctuations in stratus coverage.

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TP-80-02
June 1979

PACIFIC MISSILE TEST CENTER
Point Mugu, California 93042

DIURNAL MOTIONS OF COASTAL STRATUS

By

THOMAS F. LEE

SUMMARY

Diurnal dissipation of stratus over and off the southern California and Baja California coasts during two months of July is measured using GOES visual imagery. Morning inland penetration of the eastern stratus margin is favored in coastal valleys and restricted by hills. Afternoon dissipation of the margin away from land usually occurs the length of the coast, with the breadth of clearing being large off southern California, but limited both north of Point Arguello and south of San Diego.

(340-159 deg),

Decreased frequency of stratus ceilings in the southern California bight seems to be related to subsidence in the lee of the Santa Ynez Mountains to the north. With 850 mb wind flow from north and east (340°-159°), which favors lee subsidence, this region was more often stratus free than for flow from south and west (160°-339°). (160-339 deg).

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INTRODUCTION AND PURPOSE

Low visibilities and ceilings associated with typical coastal stratus and fog along the United States West Coast have long been recognized as hazards to aviation and navigation, and more recently as significant factors in the conduct of development, test and evaluation (DT&E) and fleet operations by the Navy. Although stratus has been the subject of considerable study, much vital information is still unknown concerning the normal areal boundaries of the cloud layer and how these vary with time of day, season, synoptic regime, latitude, sea surface temperature, and coastal topography. Meteorological satellites have greatly improved the capability to answer these questions. In particular, the availability of geostationary imagery allows examination of stratus behavior at intervals as short as 30 minutes.

A persistent diurnal cycle in stratus cover during the warm half of the year represents one of the most striking features of coastal stratus (Rosenthal and Posson, 1977). GOES satellite imagery reveals that onshore early morning low cloudiness dissipates quickly out to sea during daylight hours, usually leaving a strip of clearing just offshore by afternoon. The purpose of this study is to investigate statistically the normal limits of these daily fluctuations in stratus coverage with the objective of providing statistical and forecast guidance for planning Naval operations off the United States West Coast.

First a basic overview of the summer climatic regime off and over the west coast is briefly provided as it relates to low cloud distribution and behavior. This includes some review of highlights of coastal stratus dissipation and formation, and its areal limits and behavior, as investigated and documented by other researchers. This report then discusses a method employed to collect relevant data from GOES imagery, and finally presents and discusses the results of this investigation into the nearshore behavior of stratus using this method.

BACKGROUND INFORMATION

West Coast Stratus Regime in Summer

From May through September low cloudiness dominates the northeastern Pacific coastal waters. To understand formation and dissipation processes in this cloud layer, it is necessary first to consider some aspects of the summer circulation.

In summer, surface air flow comes mainly from the north and northwest around the semi-permanent Pacific high pressure cell that persists in the eastern portion of the ocean. Caused by persistent subsidence aloft over the area, this high produces quite warm temperatures and low humidities. The warming and

drying associated with the subsidence would extend down to the sea surface, except that southward moving surface air assumes marine characteristics, becoming cool and moist in accordance with the prevailing field of sea surface temperatures. Thus, a well-mixed marine layer develops with roughly adiabatic lapse rate, surmounted by an extremely dry, stable layer (Neiburger et al., 1945). The height of the base of the intervening transition layer or inversion off southern California averages 1 to 2,000 feet but varies from 0 to 5,000 feet or more (Rosenthal, 1965). Below the inversion base, stratus is often present, with thicknesses being typically between 1,000 to 1,5000 feet (deViolini, 1974).

Another influential feature on the distribution of coastal stratus is a thermal trough of low pressure at the surface, over the southwestern interior of North America. Combined with the circulation around the Pacific high, the trough causes the surface isobars to be roughly parallel to the coast, in the proximity of San Francisco Bay equatorward to Baja California. The resulting circulation has an onshore component, bringing the marine layer and its associated stratus into the coastal valleys. The net transport of ocean air inland is often referred to as the "west coast summer monsoon" (Schroeder et al., 1967).

During the day, heating of the land interior accelerates this onshore flow, bringing a strong sea breeze to the coastal areas. At night, cooling of the interior may reverse the flow for a short time, bringing a weaker land breeze to the coast (particularly in southern California). Combined with effects of topography, the diurnal sea-land breeze regime results in an alternating pattern of local convergence and divergence near the shoreline (Demarrais et al., 1965).

Overland, surface flow is strongly steered by terrain features and is subject to local diurnal heating. Upper-level flow, while still affected by terrain effects and local heating to some degree, reflects the overall pattern of differential heating of land and sea. Thus, a northerly wind field exists up to about 2 km. Above this level the effect of ocean-continent differences diminishes, and a more zonal regime begins, determined by north-south temperature differences (Edinger, 1960).

Spatial variations in sea surface temperature over the eastern Pacific are also an important and sometimes controversial factor, contributing to stratus formation and behavior. A major oceanographic effect of the prevailing northerly wind field around the eastern flank of the subtropical high is the displacement of lighter, warmer surface waters westward, and the upwelling of colder subsurface waters along the central and northern California coasts. This pattern is reversed in the southern California bight, with warmer waters nearer the coast (figure 1).

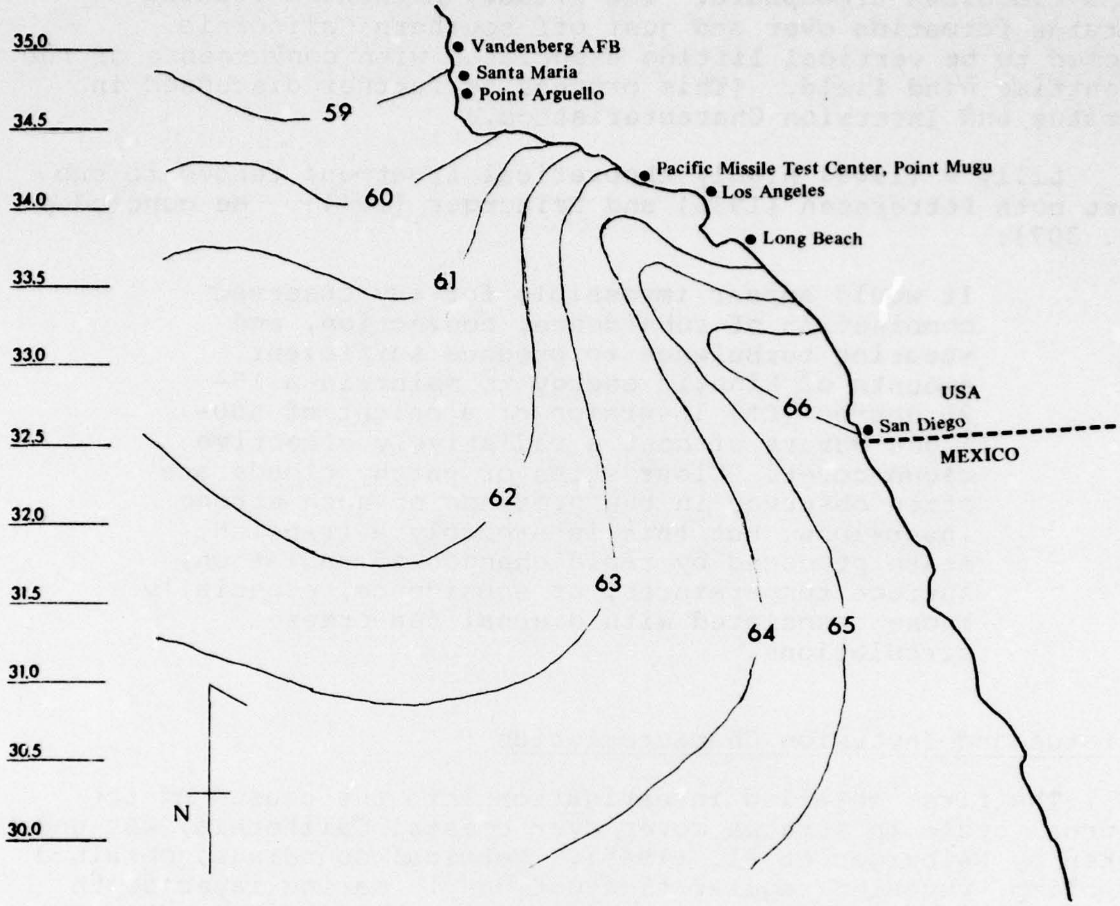


Figure 1. Mean Surface Temperature (F°), July.
Showing Coastal Southern California reference stations.

Formation and Maintenance of Stratus

Byers (1930), asserted that advection of moist air over cold coastal waters contributed to stratus formation over the central California coast. Petterssen (1938), noting a sometimes super-adiabatic daytime lapse rate in the marine layer off San Diego, proposed that convection due to warmer waters maintained the layer's depth. He also asserted that the large lapse rate of the marine layer is partly explained by strong radiational cooling from cloud tops. (Petterssen demonstrated that though the inversion is much warmer than the cloudy marine air below, its dryness precludes a downward flux of heat.)

Neiburger (1944), indicated that radiative loss from stratus tops might help thicken the cloud layer, but radiative loss from the marine layer could not by itself initiate stratus formation

in a cloudless atmosphere. The primary mechanism leading to stratus formation over and just off southern California, seemed to be vertical lifting associated with convergence of the nighttime wind field. (This process is further discussed in Stratus and Inversion Characteristics.)

Lilly's (1968) highly theoretical treatment tended to support both Petterssen (1938) and Neiburger (1944). He concluded (p. 307):

> It would appear impossible for any observed combination of subsidence, convection, and shearing turbulence to produce sufficient amounts of kinetic energy to maintain a 15-20 degree (C°) inversion of a height of 500-1,000 meters without a radiatively effective cloud cover. Clear skies or patchy clouds are often observed in the presence of such strong inversions, but this is probably a transient state produced by rapid changes of radiation, surface temperatures, or subsidence, especially those associated with diurnal sea-breeze circulations.

Stratus and Inversion Characteristics

The first detailed investigation into the causes of the diurnal cycle in stratus cover over coastal California, was undertaken by Neiburger et al. (1945). Vertical soundings, obtained by blimp, revealed regular fluctuations in marine layer depth along the coast. A theory was developed to link these changes to stratus dissipation and formation.

Their observations indicated a mean trough in the inversion height just off the southern California coast, with the marine layer becoming deeper both onshore and farther out to sea. Diurnal changes in the depth of the marine layer, which were superimposed on the mean pattern, were believed to be closely tied to the normal sea breeze regime. The authors reasoned that the afternoon sea breeze diverges as it spreads into the inland valleys; this contributes to a vertical shrinking of the marine layer along the coast resulting in dissipation of stratus. At night after initiation of a land breeze, the resulting convergence then deepens the marine layer in coastal regions allowing stratus to reform. This cycle has spatial as well as temporal dimension. In coastal regions, the inversion is highest in early morning and lowest in late afternoon. While over inland areas, the inversion is lowest in morning and highest in afternoon when mixing due to daytime heating is greatest.

The inversion height and associated stratus coverage was also observed to be subject to important day-to-day fluctuations, days with low inversions being relatively clear and those with high inversions being relatively cloudy. But while daily stratus dissipation seemed to be related to variations in the sea breeze, day-to-day changes in inversion depth (and therefore stratus coverage) were linked to the magnitude of the pressure gradient between the coast and desert regions--the stronger the gradient, the deeper the coastal inversion.

Neiburger et al., distinguished between stratus formation processes in southern California and those in central and northern California. Abrupt turning of the coast at Point Conception, the presence of islands, and the extended region of shallow water influencing the water temperature distribution along the coast, all contributed to differentiating the behavior of the stratus south of about 34.5°N. In northern and central California, formation and dissipation of stratus was thought to be mainly an advective phenomenon, while in southern California vertical motion within the marine layer was seen as more important.

Edinger and Wurtele (1971), under contract to the Pacific Missile Range, relied on airplane soundings to determine the topography of the inversion base over the southern California off-shore waters. Their findings supported the earlier observation of Neiburger et al. (1945), that the inversion base fluctuates diurnally, reaching its highest level near the coast in morning and then dropping rapidly in afternoon. Large diurnal falls in marine layer depth found at the mouths of large coastal valleys also were seen as support of the idea that the divergence of the sea breeze into the coastal valleys accounts for afternoon shallowing in this layer. Their findings, in general, corroborated the earlier finding of a large trough in the inversion height just off the southern California coast but superimposed with fairly large mesoscale variations as shown in figure 2.

Marine Layer Modification by the Arguello Headland

Several authors have noted that the west-to-east headland north of the Santa Barbara Channel exerts an effect on the flow entering the area from the northwest, altering the marine layer downstream. (This topographic feature is referred to here as the "Arguello headland" after Point Arguello, which juts out to sea at its western edge.) Formed by the narrow Santa Ynez mountain range, the Arguello headland is not over 700 meters high; still, its west-to-east orientation, coupled with the extreme stability of the prevailing airmass, make it a significant obstacle to northwesterly flow headed for the southern California bight.

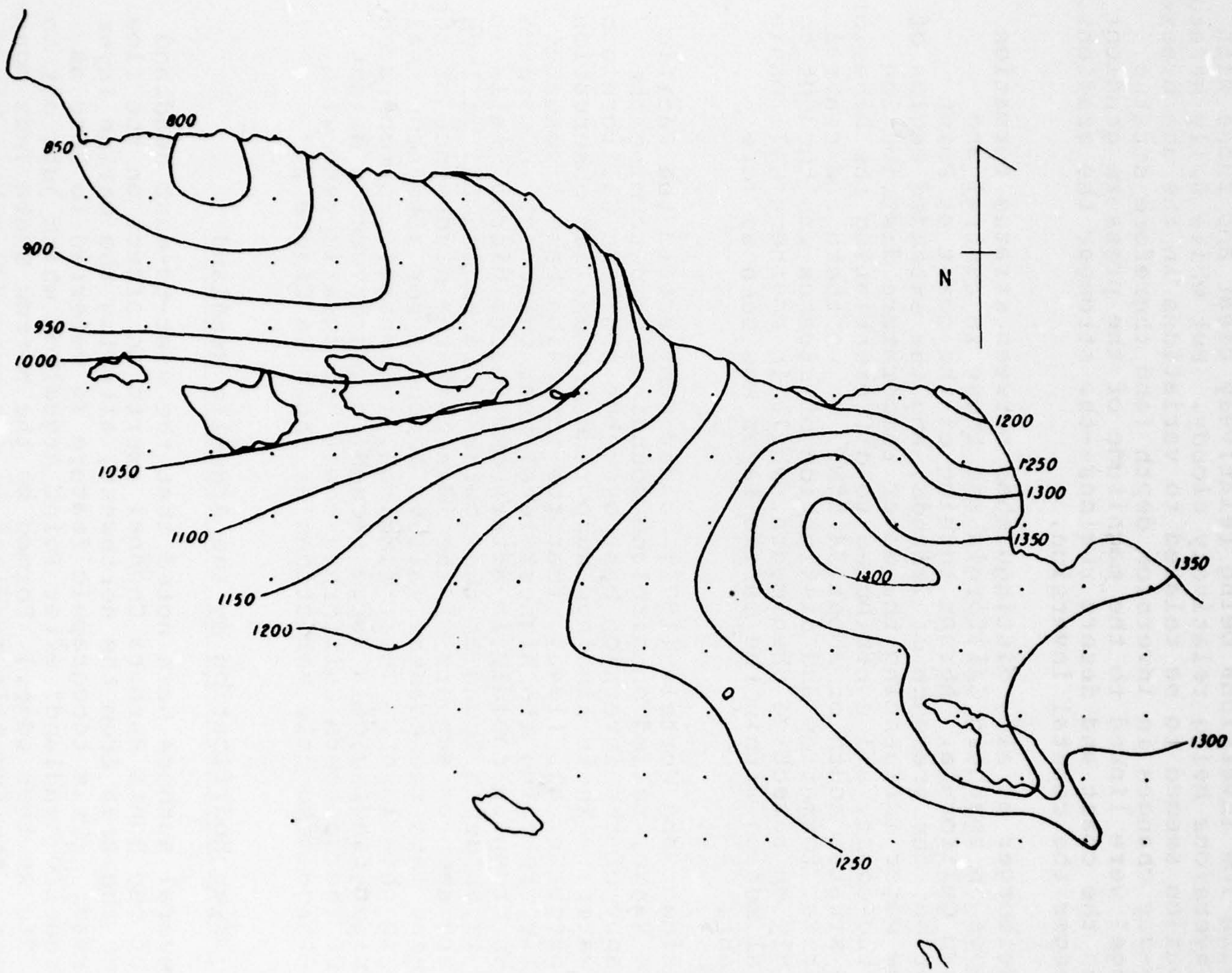


Figure 2. Contour Map of Mean Top of Marine Layer in Feet, August - September, 1966 Daytime. *(from Edinger and Wurtele, 1971)*

Using airplane soundings, Smith et al. (1964), inferred that northwesterly flow off the Pacific induced large amplitude, vertical waves in the lee of the headland, the exact amplitude and number of waves depending on stability and wind shear. Subsidence and marked warming were often observed on the south side.

Roberts et al. (1970), found that the Arguello headland and the Buchon headland to the north modify the climatic pattern, resulting in colder temperatures on the upwind side, with warmer temperatures downwind (probably resulting from subsidence). An area of increased wind flow could be expected in the transition zone. The inversion base was found to be usually higher upwind than downwind; also a small area of clearing in stratus cover was often present just to the lee of both headlands. Figure 3 presents inversion height data for the two headlands for a summer day, considered representative of the usual pattern. Roberts et al. proposed a simple model to explain the observed conditions near a headland (figure 4). Convergence occurs upwind as a result of orographic lifting, and divergence along with a mechanically-induced eddy developing downwind.

Edinger and Wurtele (1971), observed an overall inversion height minimum in the Santa Barbara Channel just south of the Arguello headland. The minimum averaged only about 800 feet compared to heights of 1,000 to 1,400 feet over most of the rest of the area. They further observed (p. 12):

> Often the very shallow marine layer in the Santa Barbara Channel was topped by a moist inversion and at times so was the much deeper marine layer off the Los Angeles coastline. This suggests that at times very active subsidence takes place over the coastal waters well below the top of the moist layer of air that is being delivered from the northwest around Point Arguello.

Moist inversions were also found by Neiburger (1945), but were attributed to moisture evaporated from mountain areas.

Edinger and Wurtele (1972), also discussed frequent stratus "holes" (or clear regions) in the lee of the Channel islands and headlands. Over island regions these holes were shown to be accompanied by a lower inversion height, and were attributed to forced subsidence as the upper flow descends after crossing island terrain. Low cloudiness was considered to dissipate as a result of mixing of dry inversion layer air with the moist layer below. Headlands were believed to exert a similar effect on cloudiness downstream.

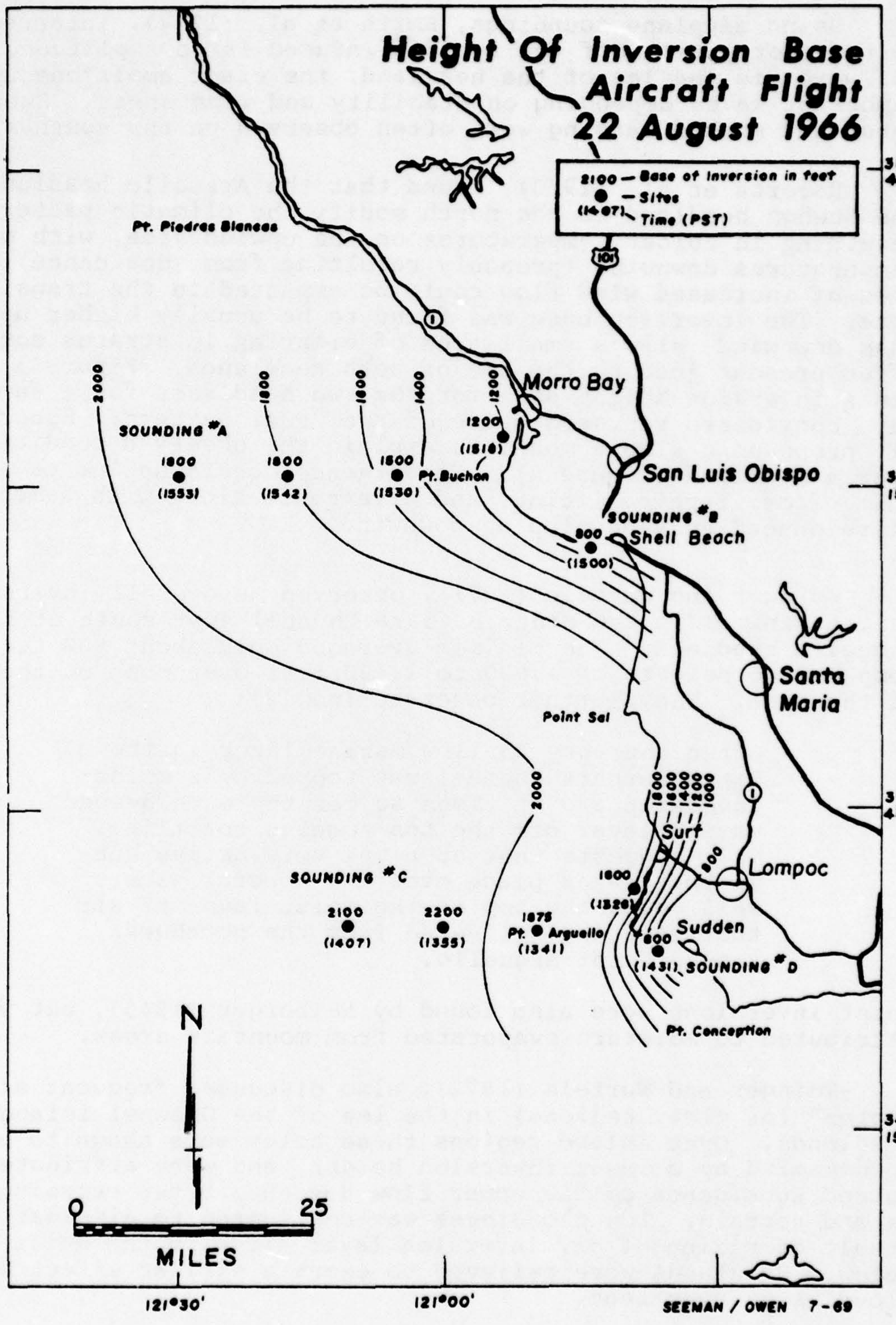


Figure 3. Height of Inversion Base (Aircraft Flight, 22 August 1966).
(from Roberts et al, 1970)

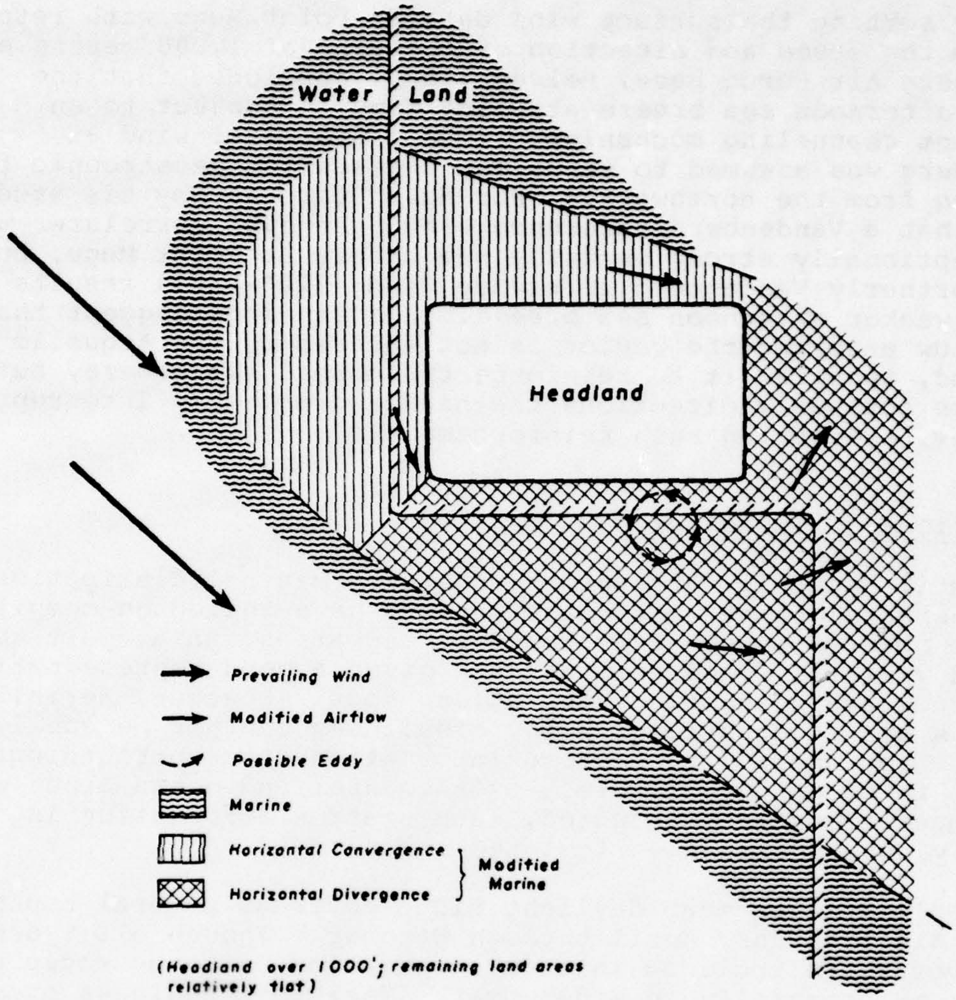


Figure 4. Climatic Modification by a Headland.
(from Roberts et al, 1970).

Weather Type by Upper Wind Direction

Though the strength of the surface wind over coastal areas should correlate with the coast-desert pressure gradient, Neiburger et al. (1945) asserted that the appraisal of a favorable stratus situation is difficult to make from surface wind flow alone. This is due to rapid fluctuations in the sea-land breeze regime as a result of daily surface heating and cooling. However, the wind field aloft (at approximately 5,000 feet) gives a good approximation of mesoscale flow within the marine layer. In general, Neiburger et al. showed that when upper wind flow comes from the north through southeast, stratus is generally absent because the flow is offshore. If the upper wind flow comes from the south through northwest, stratus is much more prevalent.

By sorting the surface wind data at Point Mugu with reference to the speed and direction of the wind at 1,000 meters at Vandenberg Air Force Base, Helvey (1970) concluded that the normal afternoon sea breeze at Point Mugu is subject to an important channeling mechanism. (The 1,000 meter wind at Vandenberg was assumed to represent undisturbed geostrophic flow arriving from the northwest.) For March through May his study shows that a Vandenberg reference wind near 300° correlates with an exceptionally strong westerly sea breeze at Point Mugu, but a more northerly Vandenberg reference wind (320°-030°) results in a much weaker afternoon sea breeze. His findings suggest that 300° flow entering the region is not altered by the Arguello headland, enabling it to reinforce the normal sea breeze, but for more northerly directions the headland probably interrupts the flow, preventing such reinforcement.

Conventional Climatologies

Until recently, attempts to describe diurnal dissipation and other aspects of the west coast stratus have relied on compiled surface observations. Over coastal land areas, an airport summary of visibility and ceiling data gives a good representation of diurnal and seasonal cycles at one spot. However, aerial patterns and fluctuations in low cloudiness can not be easily derived from these data because information from surrounding regions is often unavailable. Over coastal and ocean areas where Naval operations are conducted, such station information is entirely absent except on isolated islands.

Table 1 gives mean daylight cloud cover at several southern California stations, April through October. Though all types of cloud cover are included in this information, stratus cover predominates, especially in mid-summer. Maximum cloudiness occurs in May; mean cloudiness abruptly decreases from June to July, with a minimum in August.

Table 1. Mean Daytime Sky Cover (tenths), 1941-1970.

	APR	MAY	JUN	JUL	AUG	SEP	OCT
Santa Maria (Airport)	4.5	4.5	3.8	3.4	3.4	3.6	3.6
Los Angeles (Civic Center)	4.7	4.9	4.3	2.7	2.6	3.0	3.8
Los Angeles (Airport)	4.8	5.3	5.2	4.1	3.9	4.3	4.4
Long Beach (Airport)	4.4	4.9	4.7	3.4	3.2	4.1	4.4
San Diego (Airport)	5.2	5.7	5.5	4.6	4.1	4.1	4.2

From U.S. Department of Commerce (1977a)

The diurnal cycle in cloudiness, though present in every month, increases in June and becomes most pronounced in July and August before diminishing again in September (table 2). Lea (1968) noted that at Point Mugu the greatest and least yearly mean incidence of overcast occur a few hours apart in August.

Table 2. Percent of Sky Conditions 3/10 or Less at 0700 and 1600 PST, 1951 - 1960.

		APR	MAY	JUN	JUL	AUG	SEP	OCT
Los Angeles	0700 PST	27	31	23	27	23	31	36
(Airport)	1600 PST	50	57	71	83	77	77	62
	Change	23	26	48	56	54	46	26
San Diego	0700 PST	20	22	13	18	13	35	36
(Airport)	1600 PST	51	62	67	75	77	79	66
	Change	31	40	54	57	64	44	30

From United States Department of Commerce (1962)

At sea, statistical information concerning cloud cover can be gathered from ship reports and sorted with respect to position; often these data are compiled in one degree or five degree quadrangles. Interpretation of such results is made difficult, since every sub-area within a quadrangle is not necessarily evenly represented by reports. For example, in a quadrangle with an east side next to the shoreline, many more reports might come from that side, significantly biasing the data. Furthermore, these data are usually compiled only by month (not time of day), so information concerning diurnal trends is unavailable.

A map prepared from United States Navy ship reports (Naval Weather Service, 1971) for one-half degree quadrangles (figure 5) shows the occurrence of no ceiling (cloud bases greater than 8,000 feet or sky cover less that five-eighths) west of the California coast south of 35°N for July. Only those quadrangles with more than 25 observations were used to construct isolines. "Clear" skies are much more frequent inside the southern California bight than elsewhere, particularly just south of the Arguello headland. The region of strongest gradient between more prevalent cloudiness to the west and less cloudiness to the east, begins at the western edge of the headland and extends southeastward.

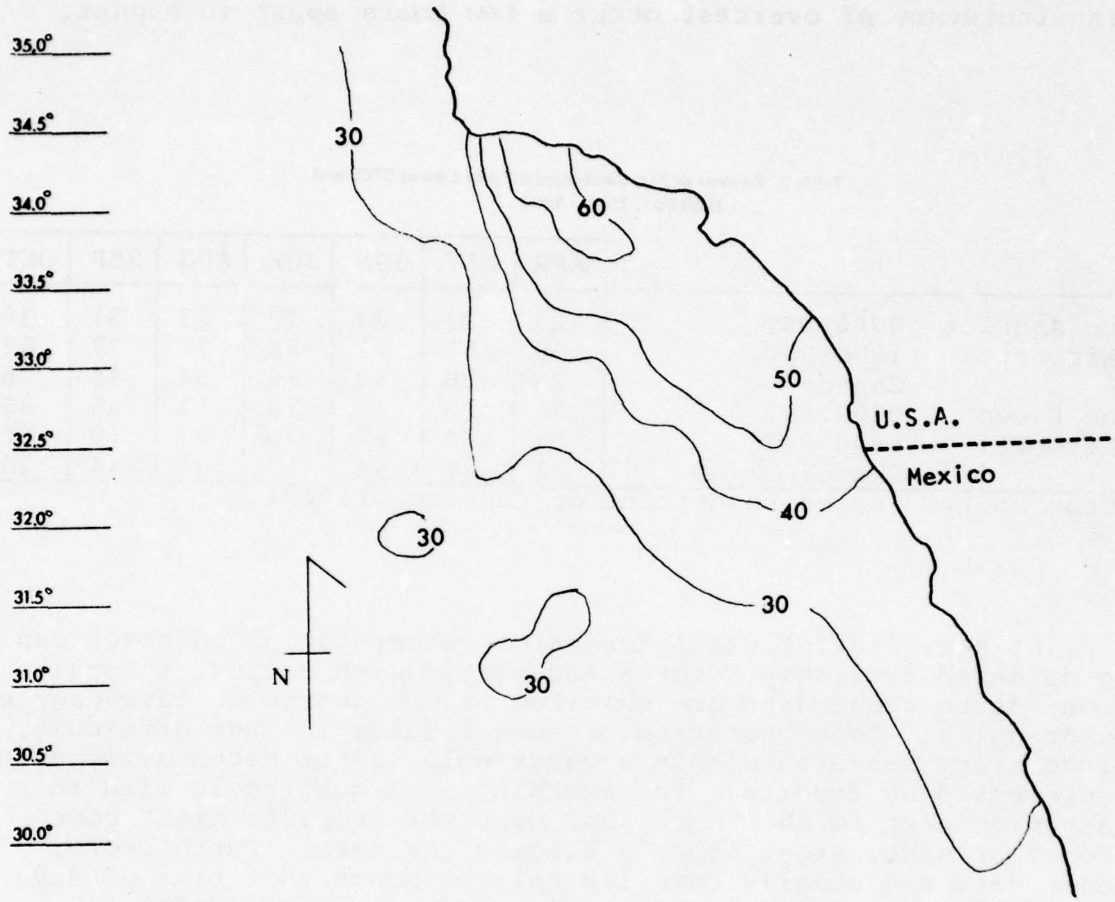


Figure 5. Frequency of No Ceilings Off Coastal Southern California, July.
(from Naval Weather Service, 1971).

Meteorological Satellites

Meteorological satellites offer the best opportunity of remotely sensing cloud coverage over ocean areas in which the Navy operates. The earliest observations were made by Television and Infrared Observation Satellite (TIROS), commencing in 1960. Satellites in this series operated in prograde orbits at between 48° to 58° from the plane of the equator. Sun synchronous and geostationary satellites comprise two basic types of contemporary satellite systems. Both provide excellent sources of stratus cloud data.

The following sun synchronous satellites are polar orbiting (800-1,500 km altitude) and view the same earth location twice in a twenty-four hour period:

1. (ESSA) After the Environmental Science Services Administration,
2. (NOAA) After the National Oceanic and Atmospheric Administration,
3. Nimbus,
4. Defense Meteorological Satellite Program (DMSP).

Geostationary satellites are in equatorial orbits (about 36,000 km altitude) synchronized with the rotation of the earth. Applications Technology Series (ATS), which became operational in 1967 is now being replaced by Synchronous Meteorological Satellite/Geostationary Operational Environmental Satellite (SMS/GOES). SMS/GOES is a system of several satellites designed for continuous monitoring of the western hemisphere. The Pacific GOES (SMS-2) has been in nearly continuous operation since 1975 at 135°W. It scans the same area of the earth (including the northeastern Pacific and most of the United States) every half hour, transmitting visual and infrared digital information back to earth.

Early Satellite Investigations

The lack of good surface observations over much of the ocean area under investigation has led to several studies employing satellite imagery. (Three of them are masters theses--at UCLA, San Jose State University, and the Monterey Naval Post Graduate School.) These have sought to link the observed aerial patterns in low cloudiness with such factors as sea surface temperatures, wind divergence, and synoptic disturbances. A brief review of these studies follows.

Dvorak (1966), in a qualitative discussion of west coast stratus patterns based on TIROS imagery, noted a large area of "inversion dominated" clouds often banked up against the coasts of California and Baja California with its variable northern boundary sloping off toward the southwest. This wedge of cloudiness extends further north and is more persistent during summer. The clouds are usually stratiform near the coast and more cumuliform seaward.

Gerst (1969) examined a number of warm season Nimbus and ESSA satellite pictures, and plotted a frequent pattern of low cloud coverage (figure 6), similar to that described by Dvorak (1966). Included on this chart are surface isobars and sea surface isotherms usually associated with this pattern. The northern tip of the stratus is most frequently located between 35°N to 41°N, but can occur from Baja California in the south, to as

far north as Washington state. Southward from this northern tip, the width of the low cloud deck gradually widens, occupying an increasing portion of the offshore waters. The only significant break in the low cloud overcast appears in the southern California bight.

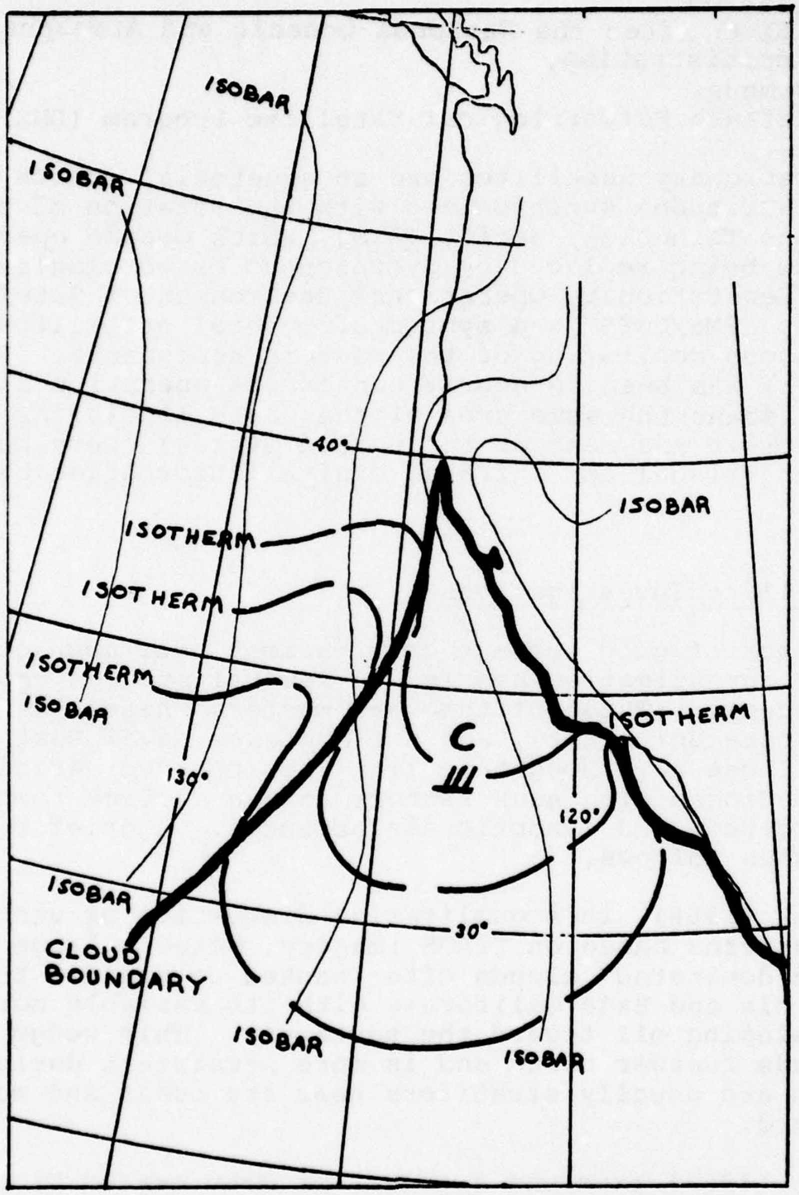


Figure 6. Typical Stratus Pattern with Corresponding Surface Isobars and Sea Surface Temperatures (SST) Pattern. *(from Gerst, 1969).*

The northern limit of the stratus-covered area was thought by Gerst to be controlled by the surface pressure field with its northern tip coinciding with an eastward bend in the isobars (figure 6). However, Gerst argued that the western boundary is generally governed by the sea surface temperature distribution, such that stratus coverage coincides with a southward-moving tongue of cold water transported by the California current. The boundary between clearing over the ocean areas to the west and low cloudiness to the east is usually quite sharp off the central and northern California coasts. A thin strip of coastal stratus along the northern and central California coast was believed, by Gerst, to be related to intense local upwelling of cold water along that coast, contributing to the formation of coastal stratus and fog. The opposite effect was thought to prevail off southern California: subdued upwelling leads to warmer sea surface temperatures, and stratus formation is discouraged.

GOES Investigations

The ability to statistically describe diurnal and other rapid changes in cloud cover over ocean areas, requires the time-lapse continuity provided by GOES imagery at 30-minute intervals. In a recent effort to describe the normal spatial pattern of low cloudiness off the west coast, Simon (1977) divided the ocean off the California coast westward to 132°W into one degree quadrangles. Inspecting GOES visual and infrared imagery, he prepared charts to describe mean cloud coverage. Two regions of interest are defined by Simon in figure 7. The first is a major trough in mean low cloud frequency off the northern and central California coasts at about 125°W, sloping slightly from northeast to southwest. The second feature of note is a local minimum in low cloud frequency inside the southern California bight. Both of these areas of relatively infrequent stratus also appear in the other stratus season months of May, June, August, and September. The local minimum in the southern California bight is particularly persistent during these months.

The area of minimum cloudiness at 125°W appears to be in agreement with the area of reduced cloudiness that appears seaward of a wedge of coastal low cloudiness, discussed earlier by Dvorak (1966) and Gerst (1969). The "typical" western boundary of the stratus given by Gerst (figure 6) coincides well with a tight gradient in stratus frequency given by Simon (figure 7).

Simon hypothesized that a minimum in low cloudiness arises from a zone of maximum wind divergence at about 125°W, which develops as the surface wind field curves from northwest over open ocean to west as it crosses the California coast. This divergence maximum causes a downward sloping inversion base in this region with an accompanying decrease in cloudiness.

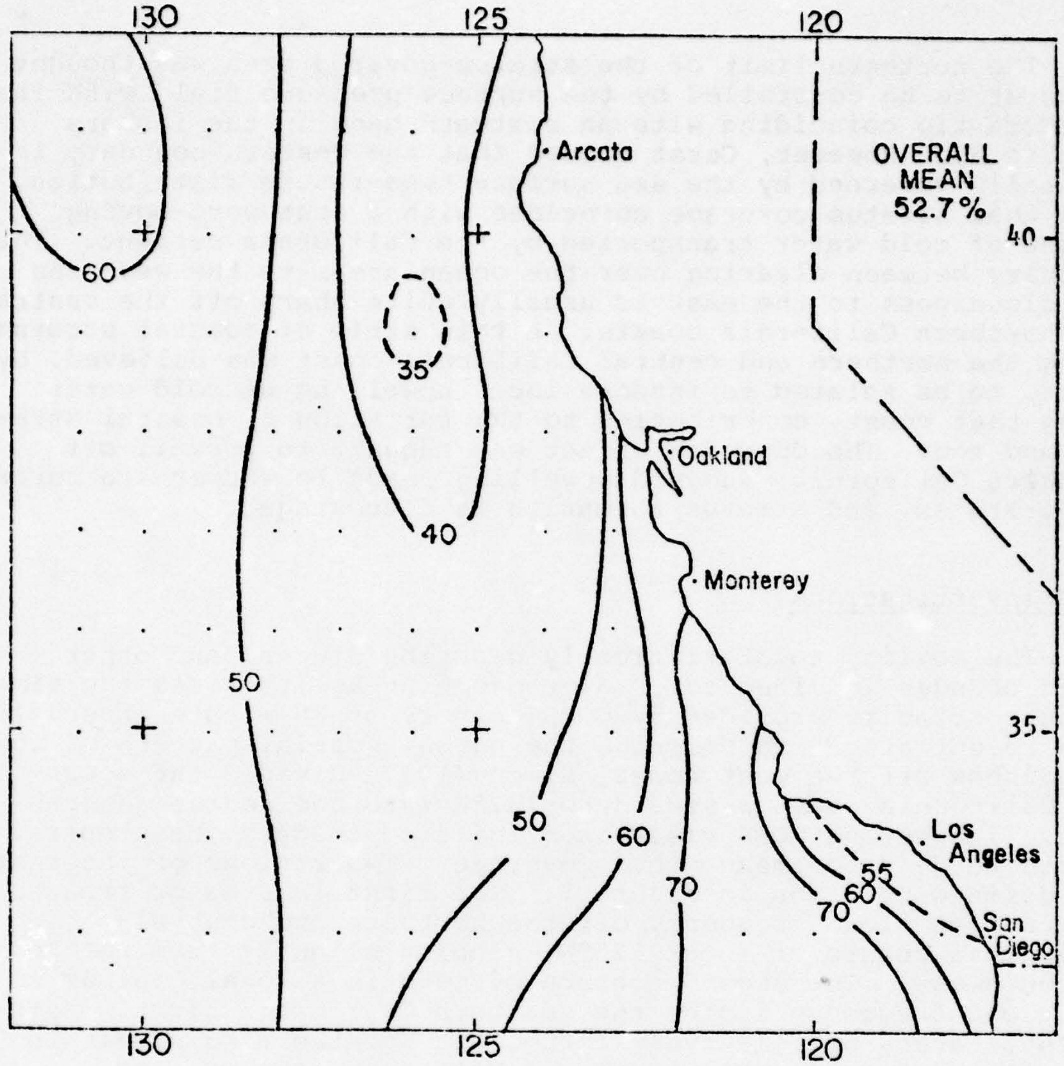


Figure 7. Mean Low Cloudiness Offshore of California (percent), July 1975.
(from Simon, 1977).

In addition to describing the overall pattern of stratus off the west coast, Simon also discussed diurnal changes in stratus cover (figure 8). For summer 1975, Simon found that diurnal burn-off (between 0745 and 1345 PST) amounted to only a five percent decrease in cloudiness off the northern California coast, while off the southern California coast south of Point Conception, it accounted for as much as a 32 percent decrease. Also documented in this report was a fairly typical case of diurnal dissipation of stratus off the California coast.

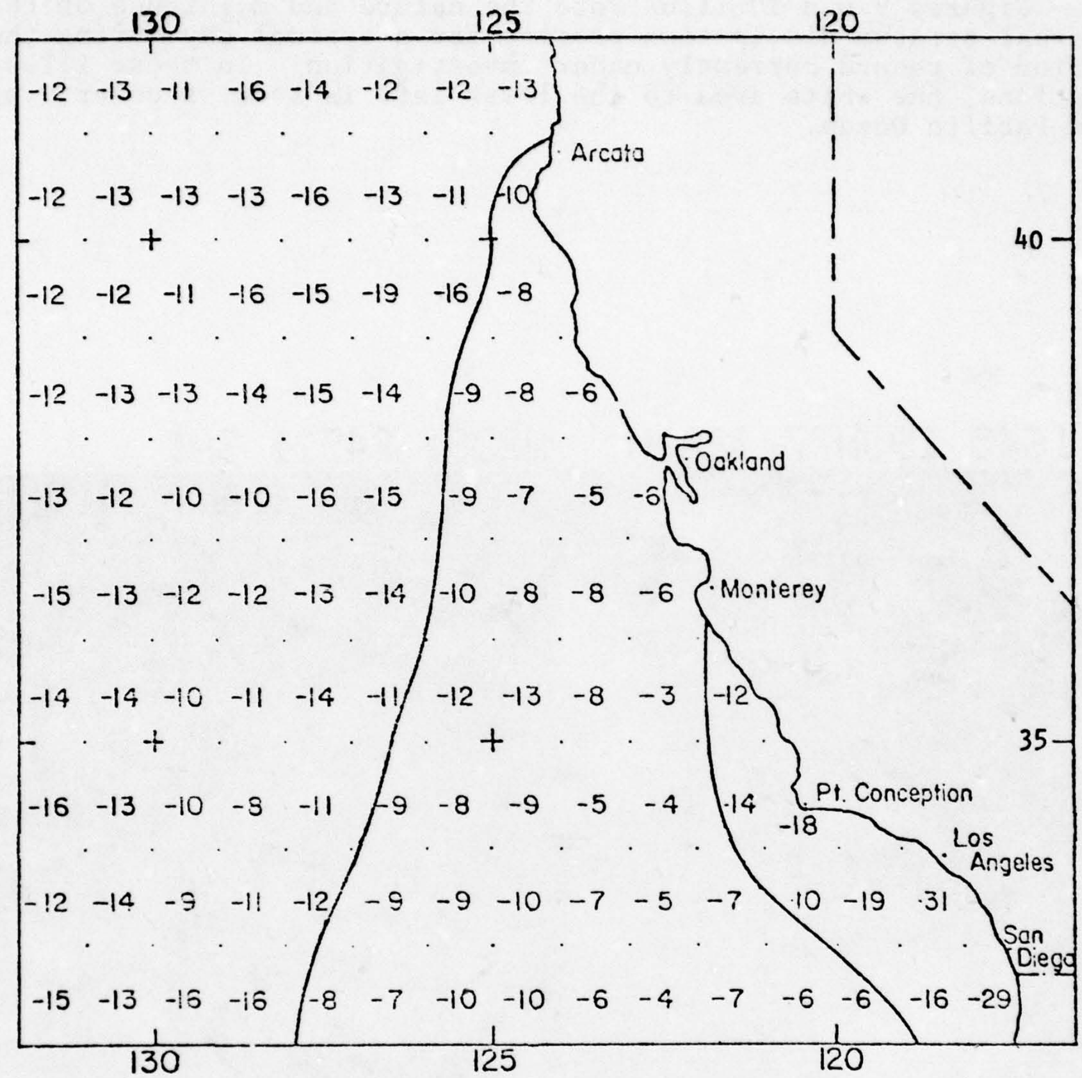


Figure 8. Mean Change in Cloudiness Offshore of California (percent) 0745 to 1345 PST May through September, 1975. *(from Simon, 1977).*

Rosenthal and Posson (1977) also documented a clear-cut example of diurnal dissipation of coastal stratus. They plotted isochrones to describe the advancement of a clear zone, which widens seaward away from the coast in the course of a summer day. The longitudinal width of the afternoon clear zone varied along the coast, becoming as great as 90 nmi off southern California. It was this observation of an unequal but regular predictable cloud dissipation over coastal waters that prompted this current investigation.

Figures 9 and 10 illustrate the nature and magnitude of the diurnal stratus dissipation process for a typical day during the period of record currently under investigation. In these illustrations, the white area to the lower left is stratus cover over the Pacific Ocean.

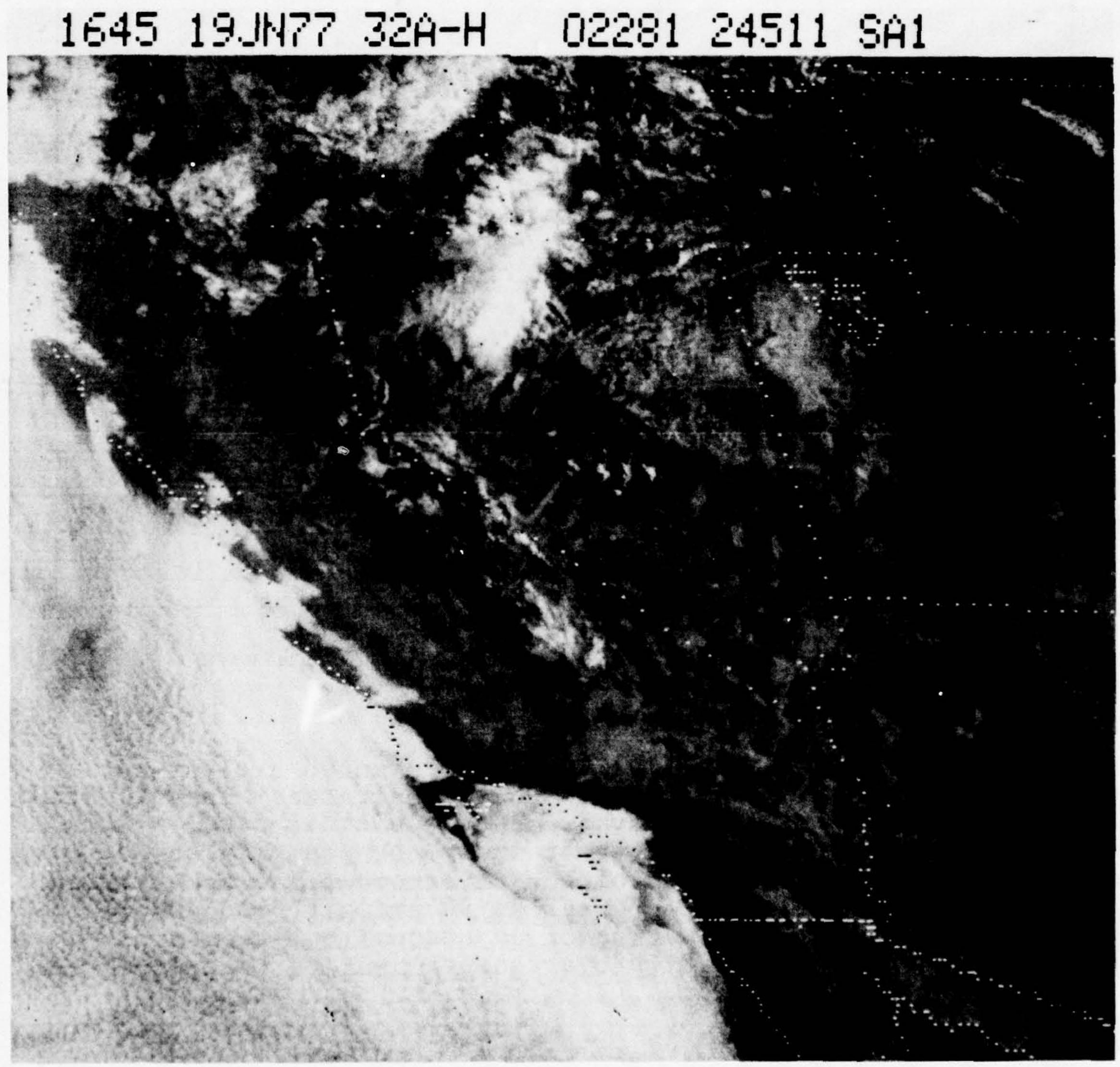


Figure 9. Morning GOES SA1 Frame, 1645Z (0845 PST), 19 June 1977.

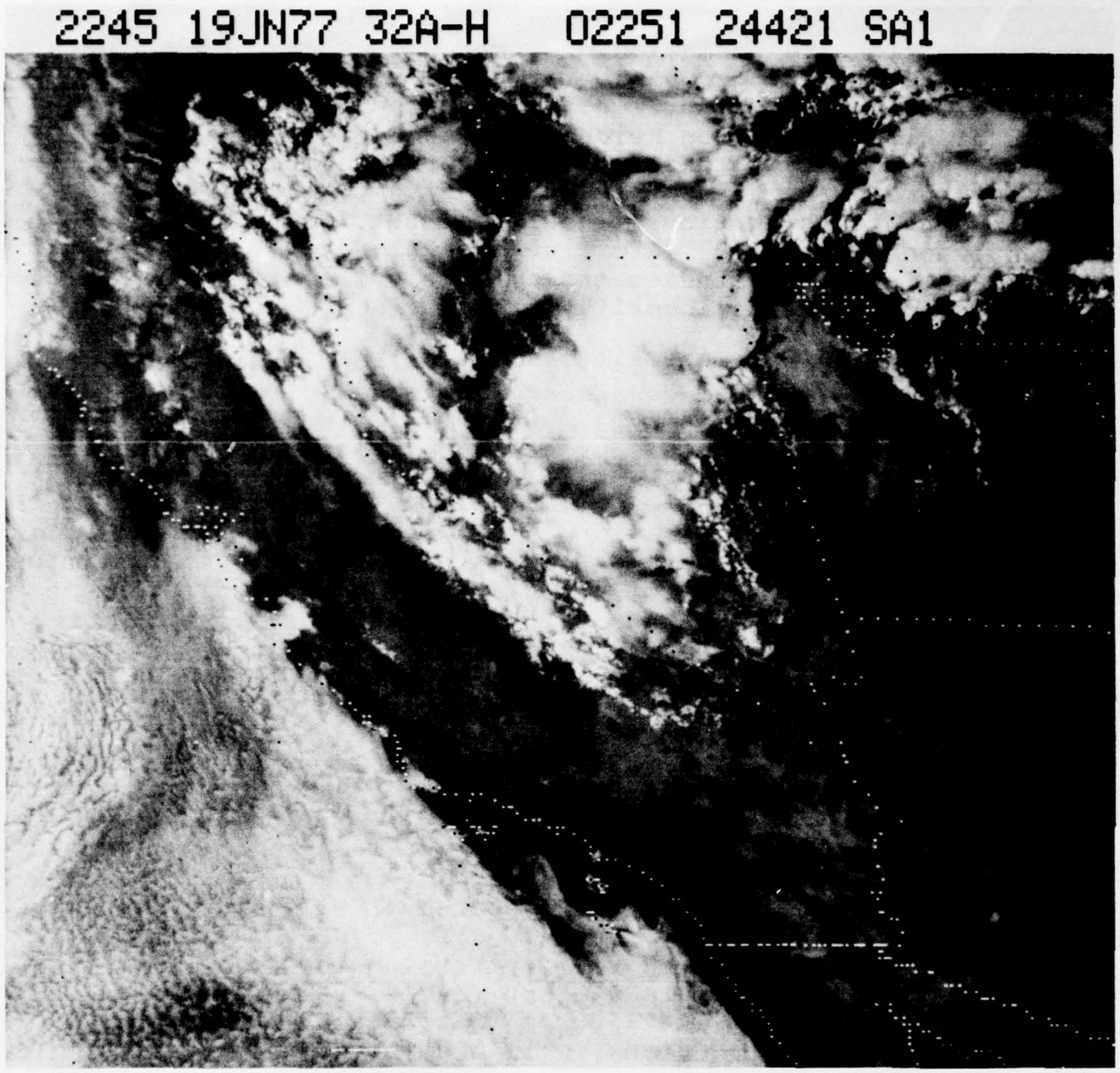


Figure 10. Afternoon GOES SA1 Frame, 2245Z (1445 PST), 19 June 1977.

At 1645Z (0845 PST), extensive low cloudiness prevails along the California and Baja California coasts. In much of central and southern California, stratus extends into the coastal valleys. Noteworthy is a pronounced clear region just southeast of Point Arguello.

In the afternoon illustration (figure 10), received at 2245Z (1445 PST), there is reduced coastal stratus, with a large area of clearing, particularly noticeable, off southern California.

Summary and Prospect

Dissipation and formation of stratus over and off southern California is linked to a number of factors, including the sea-land breeze regime, sea surface temperatures, incoming and outgoing radiation, inversion height, and synoptic-scale flow. Recently the ability to examine the importance of these factors has been improved by the introduction of satellite data, as evidenced by the investigations of Gerst (1969), Simon (1977), and Rosenthal and Posson (1977) for the coastal waters. Unfortunately, the first two studies employ data collection grid systems which are too coarse to identify intricate nearshore patterns.

Rosenthal and Posson's (1977) observations, using GOES imagery, of a latitudinal dependence to the daytime stratus dissipation over California coastal waters, provides a means of statistically describing this process. A procedure to measure the extent of this cloud motion will be presented in the following section of this report.

Both of the earlier climatological investigations of stratus cloud cover (Gerst, 1969; Simon, 1977) linked stratus incidence off southern California to sea surface temperatures. Noting a strong correlation between frequent clearing in the southern California bight and a warmer sea surface there, they argued that stratus in a marine flow entering the region must dissipate as the flow gains heat from below. However, this theory may be over-simplified, since the radiation budget of a stratus-filled marine layer is exceedingly complex (Lilly, 1968). In particular, the theory ignores the rapid loss of heat by radiation from cloud tops through the dry inversion above.

Reduced stratus incidence off southern California is also correlated with wind flow. Mean speed is considerably reduced, and the mean direction backs rapidly from northwest to west inside the southern California bight (Naval Weather Service, 1971). The effects of wind flow in this region, ignored in other satellite investigations, will also be considered in the final section of this report.

DATA AND ANALYSIS

Data Source

Because of its close-up coverage of coastal California, the GOES SA1 Sector was used as the primary source of data for this study, providing the first quantitative measure of diurnal stratus dissipation. This sector covers most of the southwestern United States, northern Baja California, and the Pacific Ocean

off California to about 125°W. Since southern California is usually free from middle and high cloudiness in summer, this imagery with resolution of about .5 nmi at the sector center provides an excellent close-up of the coastal stratus.

The visual SA1, available during daytime, provides sharp contrast between clouds, sea, and land. Through use of a scanning radiometer data manipulator at Point Mugu, enhancement curves were used to further accentuate clouds from land or ocean areas. Unfortunately, since coastal stratus is for the most part so low that it is nearly of the same temperature as the sea surface, infrared imagery available on other GOES sectors does not usually delineate stratus cover in sufficient detail to permit quantitative investigations. Thus, stratus can be well identified only from the visual data, restricting this investigation to daylight hours. Nevertheless, the period of coverage is sufficient to examine the full period of stratus dissipation as well as some of the formation.

Measurement

A system was devised by which the distance from the eastern edge of the stratus to shore could be measured along a number of geographic parallels. The twelve parallels selected included every half-degree of latitude from 30°N to 35°N; also 34.25°N was selected because of its proximity to Pacific Missile Test Center, headquartered at Point Mugu (figure 11). About two-thirds of the coast region studied lies in California with the rest being located in Baja California. The study area extends slightly north of Point Arguello so that stratus conditions upstream from the southern California bight can be analyzed.

Offshore distance to a cloud edge along a given parallel was recorded as positive, onshore distance as negative; stratus bounding the shoreline was recorded as zero distance. A clear plastic overlay, containing both the outline of the coast and the parallels used, could be referenced with respect to inland water bodies (such as the Salton Sea and Lake Tahoe), so that the position of the shoreline was still known even if stratus obscured the actual coast.

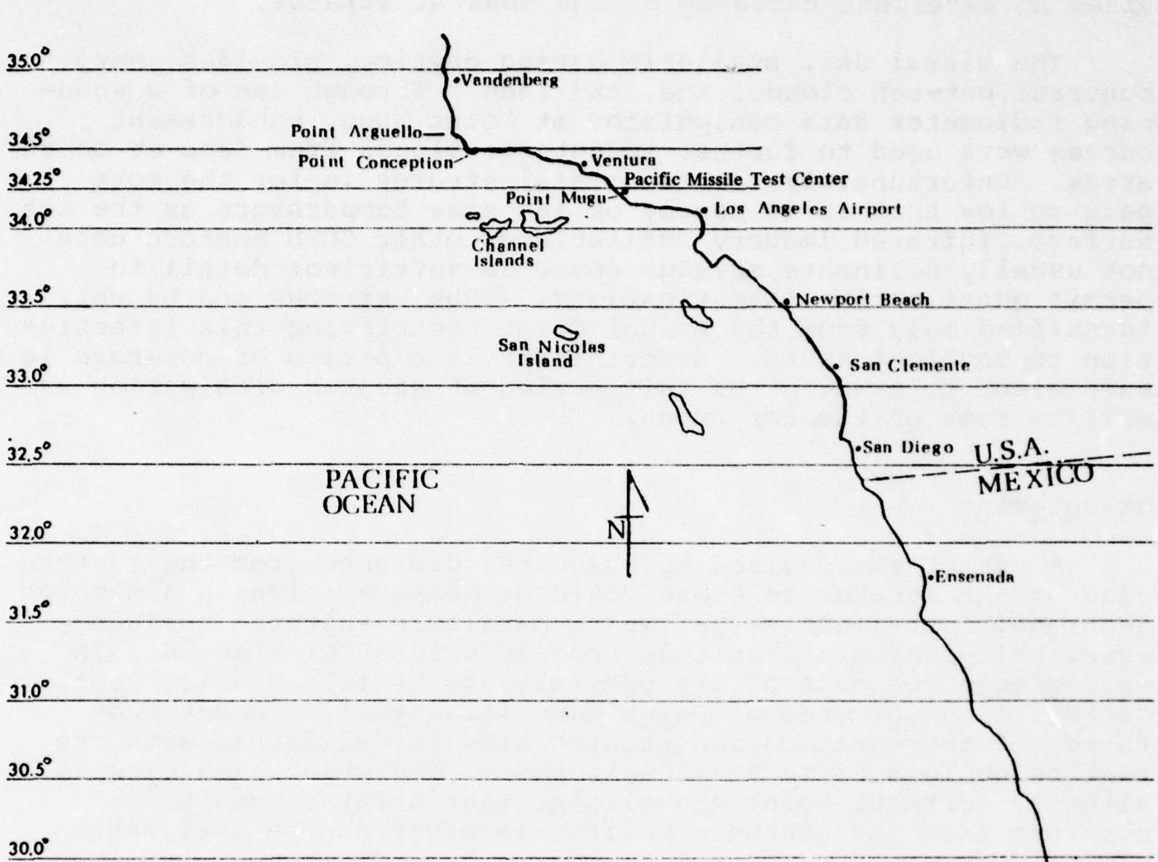


Figure 11. Stratus Condition Study Area.

Measurements in nautical miles (nmi) were assigned to the nearest multiple of five. These increments were chosen because the cloud edge was sometimes indistinct, and the limitations of the human eye precluded more exact measurement. The logic and details of this data-collecting method can best be illustrated by an example (figure 12). Here the data for a hypothetical situation are plotted, as longitudinal vectors from the coast to the edge of the stratus overcast.

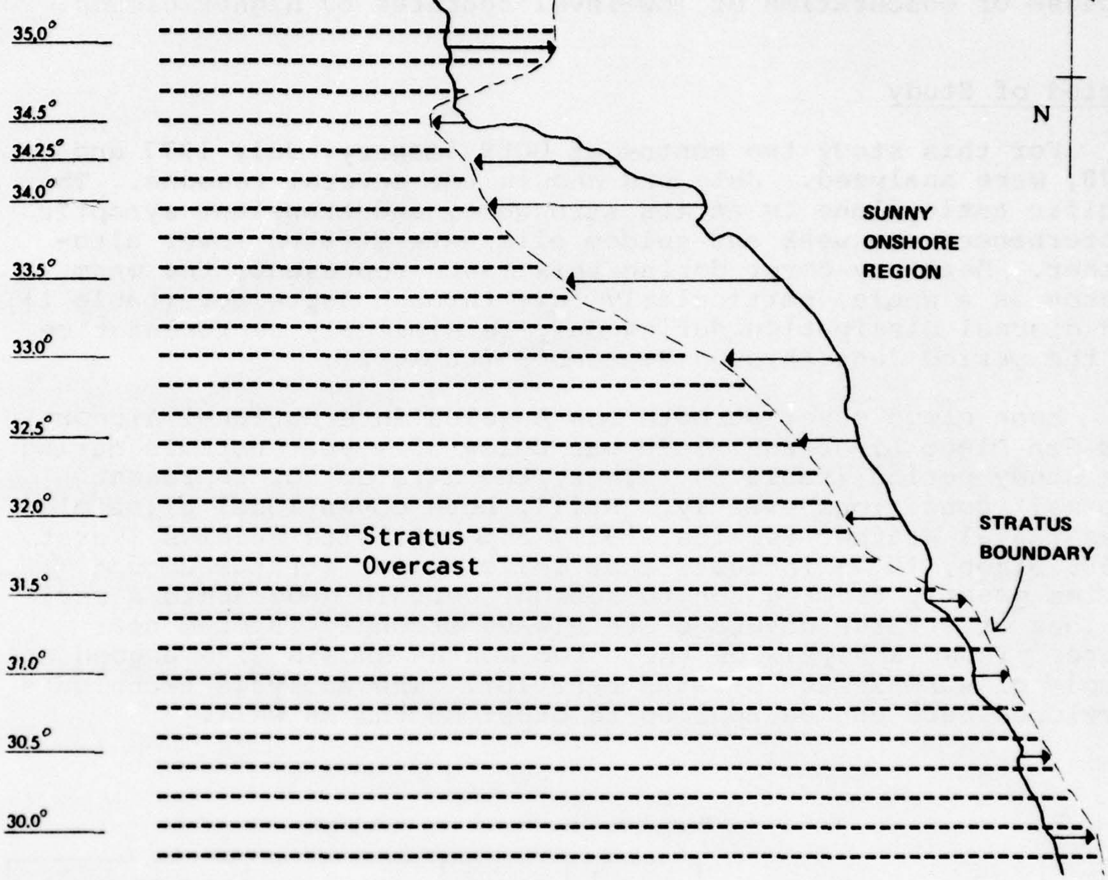


Figure 12. Example of Stratus Measurement.

Measurements were taken three times during the day: morning (0745-0845 PST), midday (1115-1215 PST), and afternoon (1445-1545 PST). These times were chosen to represent different stages in the diurnal burnoff process. The data base was reduced slightly due to missing pictures and imagery that could not be used because of obscuration of low-level features by higher clouds.

Period of Study

For this study two months of GOES imagery, July 1977 and 1978, were analyzed. July was chosen for several reasons. The Pacific anticyclone is at its strongest, and transient synoptic disturbances are weak and seldom eliminate stratus cover altogether. Mean sky cover during this month represents the warm season as a whole, particularly July through September (table 1), and diurnal dissipation during July is similarly representative of the period June through September (table 2).

Mean cloud cover at both Los Angeles International Airport and San Diego Lindbergh Field was below 30 - year normals during the study period (table 3). Thus, the data do not represent "normal" conditions exactly. Still, both coventional climatologies (Naval Weather Service, 1971) and satellite studies (Gerst, 1969; Simon, 1977) indicate that while summer stratus amount varies greatly from season to season, certain geographic distributions of stratus coverage are always strongly favored near shore. Thus, analysis of these two months should give a good sample of warm season stratus behavior. The analysis techniques developed here can be applied to other months as well.

Table 3. Mean Daytime Sky Cover (tenths), July 1977-1978.

	1977[1]	1978[2]	1977-1978	1941-1970[3]
Los Angeles International Airport	3.7	2.6	3.2	4.1
San Diego Lindbergh Field	4.5	3.4	3.9	4.6

[1] From United States Department of Commerce (1977b)
[2] From United States Department of Commerce (1978)
[3] From United States Department of Commerce (1977a)

Data Depiction

To compare the diurnal behavior of low cloudiness at varying locations along the coast, three maps were prepared (figures 13a-c), each containing six east-west cross-sections of stratus margin frequency along six latitude parallels from 30°N through 35°N. Along each parallel, frequency of stratus occurrence was plotted against distance from shore. The origin is at the coastline, positive numbers to the left of the origin representing distance offshore, and negative numbers to the right representing distance onshore. Frequency (in percent) was plotted for every 5 nmi segment. The longitudinal limits of plotted data were about 50 nmi inland (representing the farthest cloud penetration observed at any latitude in the study area) and 150 nmi offshore. Any data occurrences past 150 nmi offshore (perhaps even past the western edge of the area covered by the picture) were aggregated into a special category.

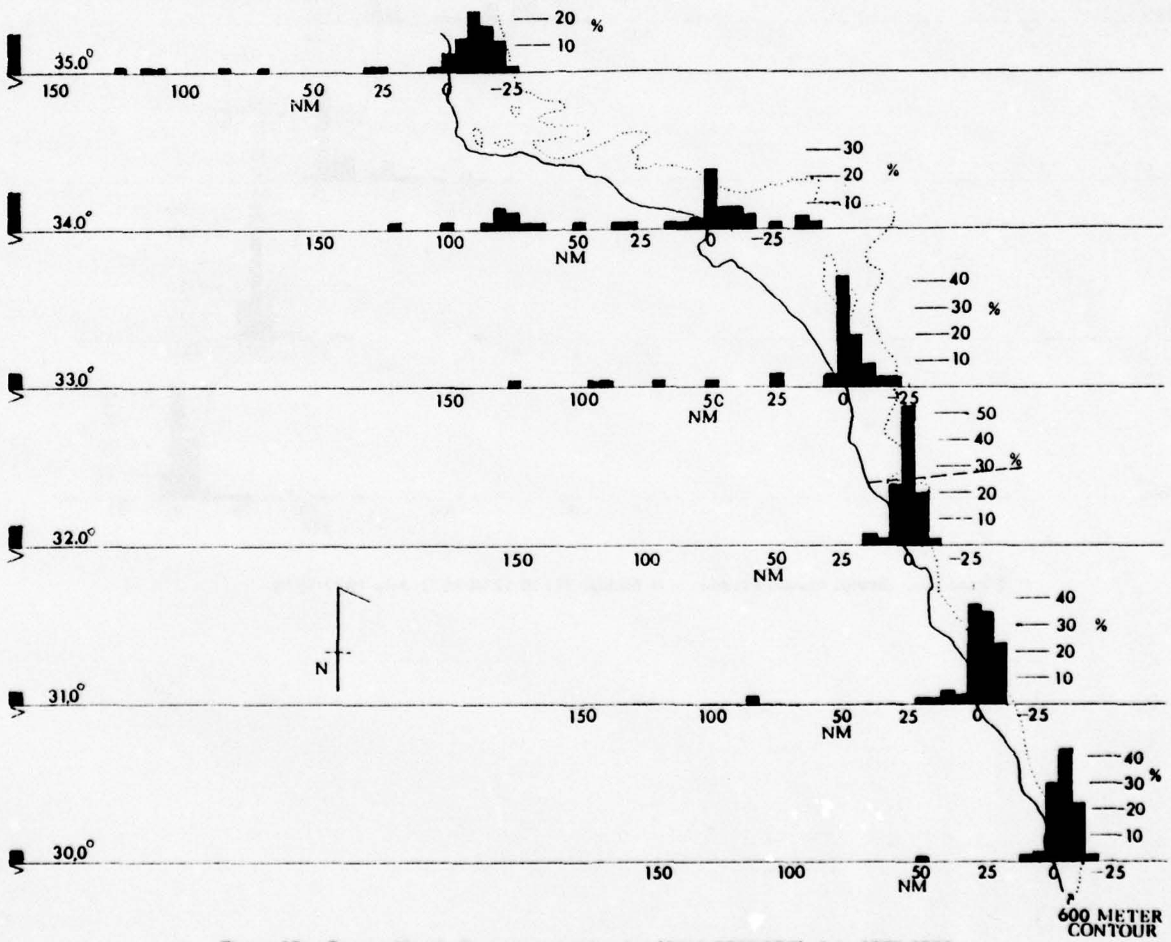


Figure 13a. Stratus Margin Frequency in Morning (0745-0845 PST), July 1977-1978.

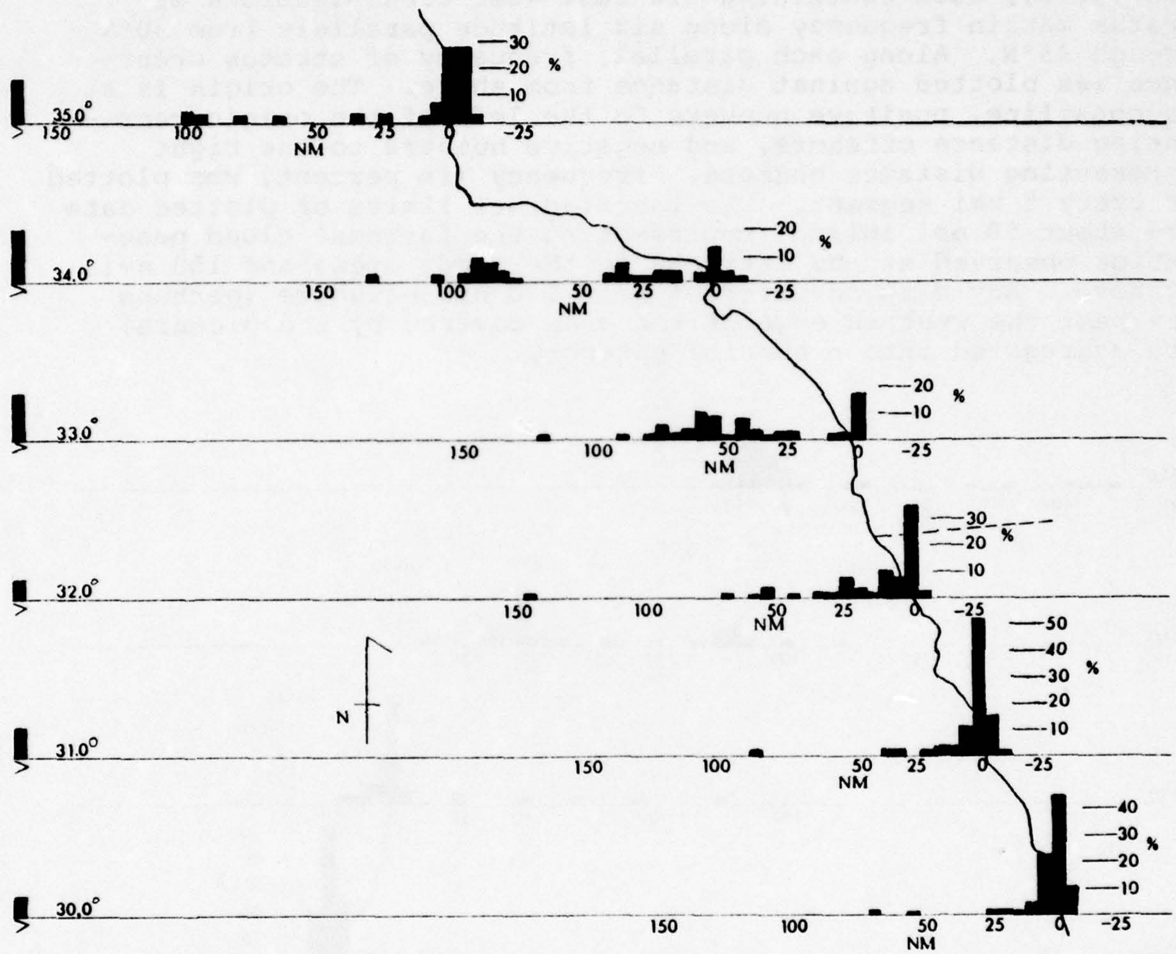


Figure 13b. Stratus Margin Frequency in Midday (1115-1215 PST), July 1977-1978.

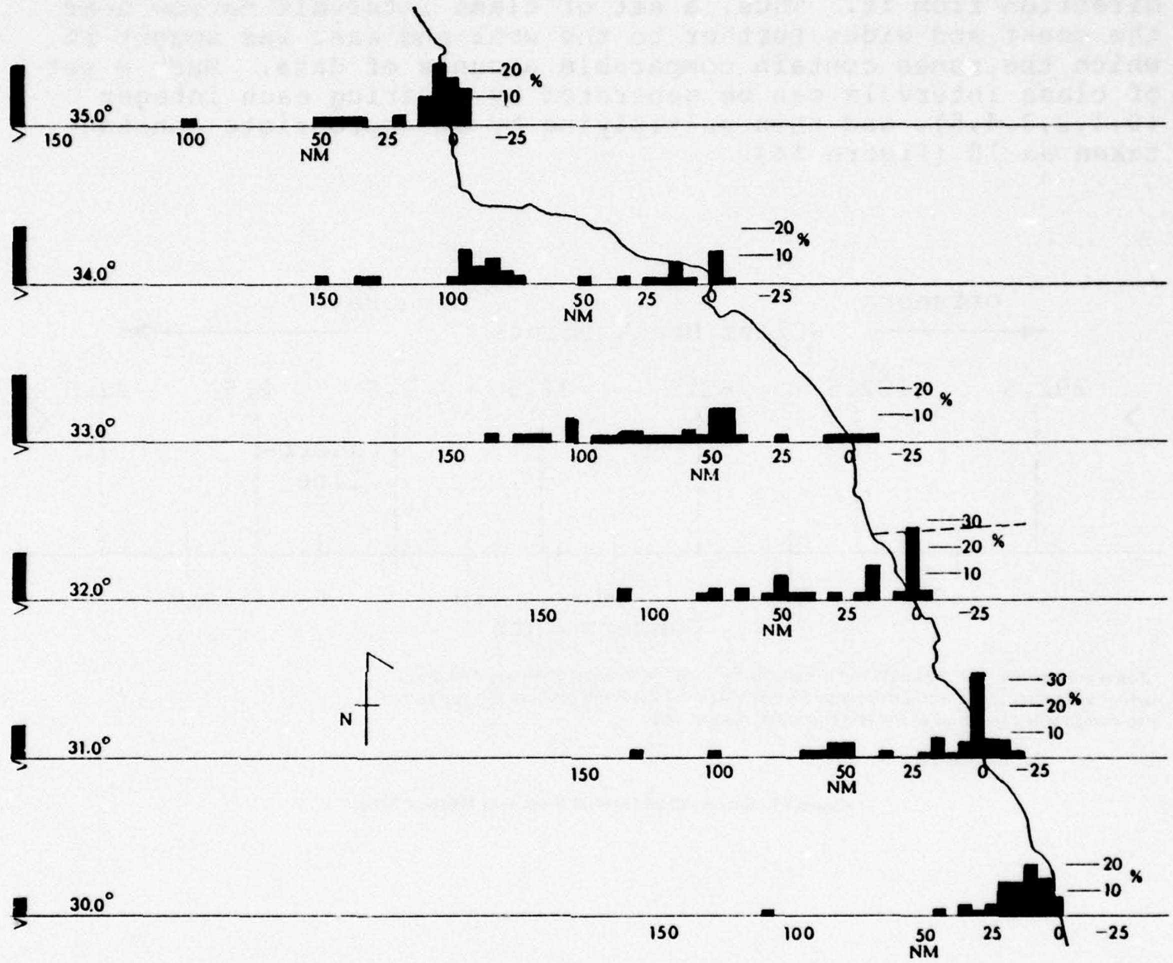
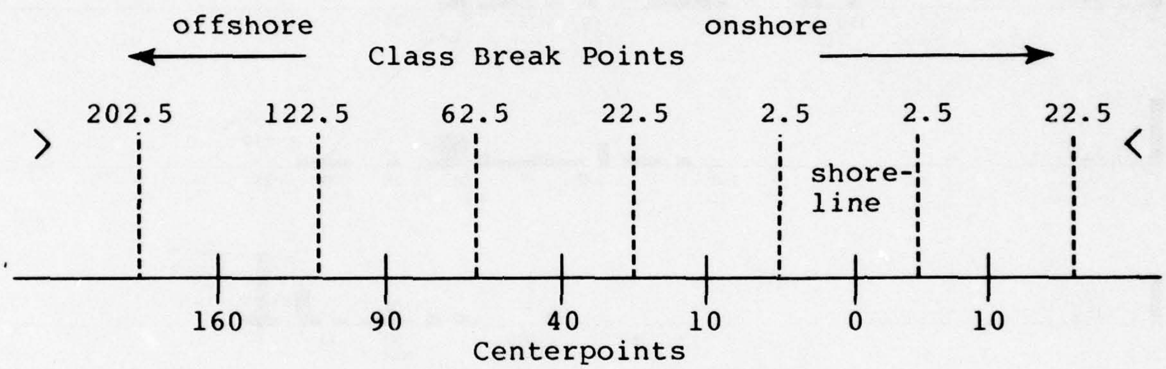


Figure 13c. Stratus Margin Frequency in Afternoon (1445-1545 PST), July 1977-1978.

Data Grouping

To facilitate further analysis, the data were grouped into zones. Preliminary inspection revealed that the eastern cloud edge is quite frequently near the coast (at all latitudes and at all times of day), but its frequency decreases rapidly in either direction from it. Thus, a set of class intervals narrow near the coast and wider further to the west and east was sought in which the zones contain comparable amounts of data. Such a set of class intervals can be generated by squaring each integer (0,1,2,3,4,5), and then multiplying by an appropriate constant, taken as 10 (figure 14).



**Zones are narrow near the coast and progressively wider inland and offshore; data cases further west than 202.5 nmi offshore or further east than 22.5 nmi onshore are aggregated into two special categories at the left and right, respectively.*

Figure 14. Sorting Class Interval System in Nautical Miles.

To obtain a sharper perspective on the normal limits of diurnal dissipation, the data for each parallel in the study area were distributed into these zones. The zone with the most frequent occurrence of the stratus margin (hereafter referred to as the "modal frequency zone") at each parallel usually contained about 25 to 50 percent of all occurrences in the distribution. Thus, the identification of this zone at a given time of day should give a good characterization of the stratus regime along a specific parallel (figure 15a-c).

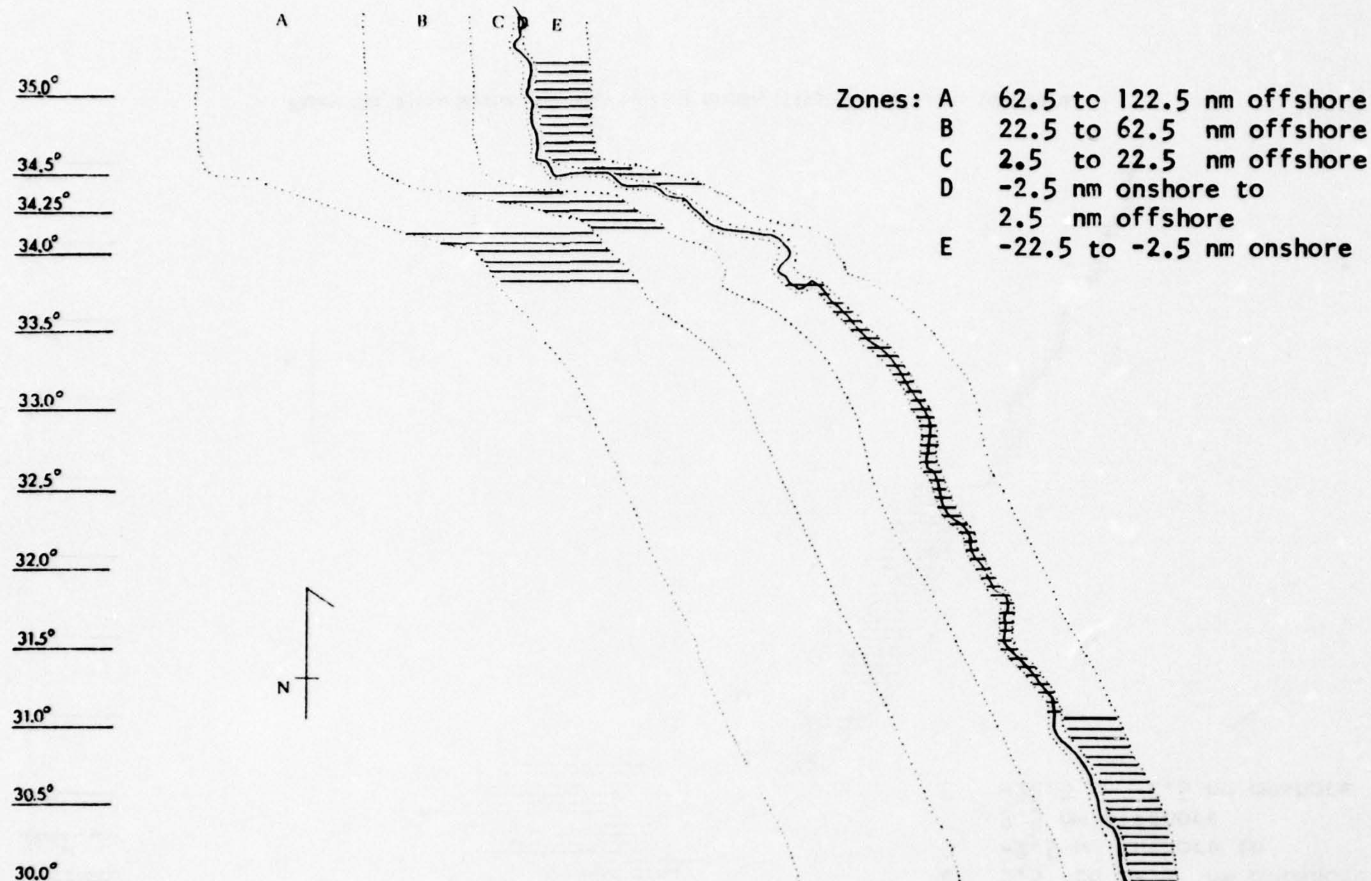


Figure 15a. Modal Stratus Frequency by Zone, Morning (0745-0845 PST), July 1977=1978.

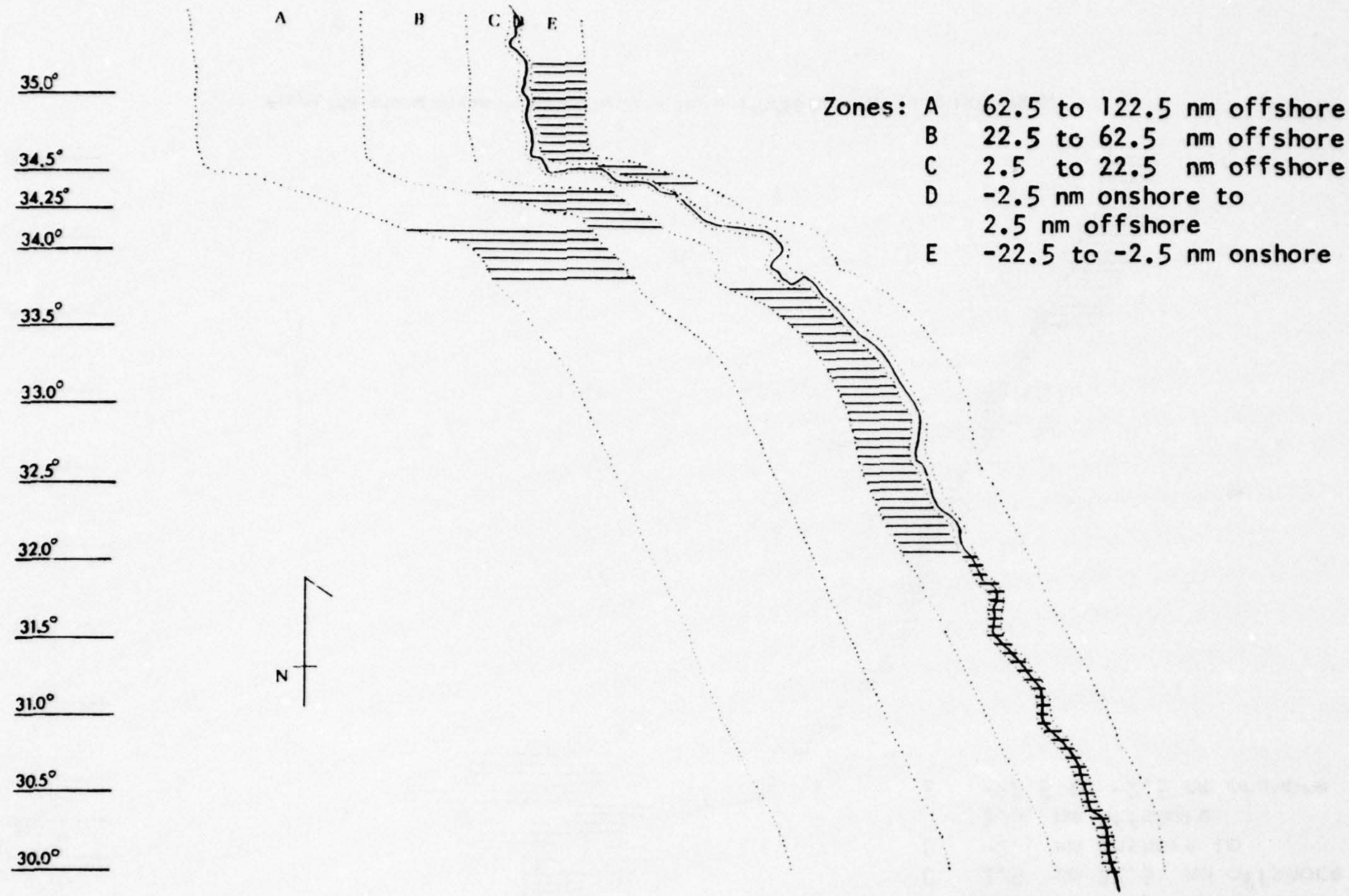


Figure 15b. Modal Stratus Frequency by Zone, Midday (1115-1215 PST), July 1977-1978.

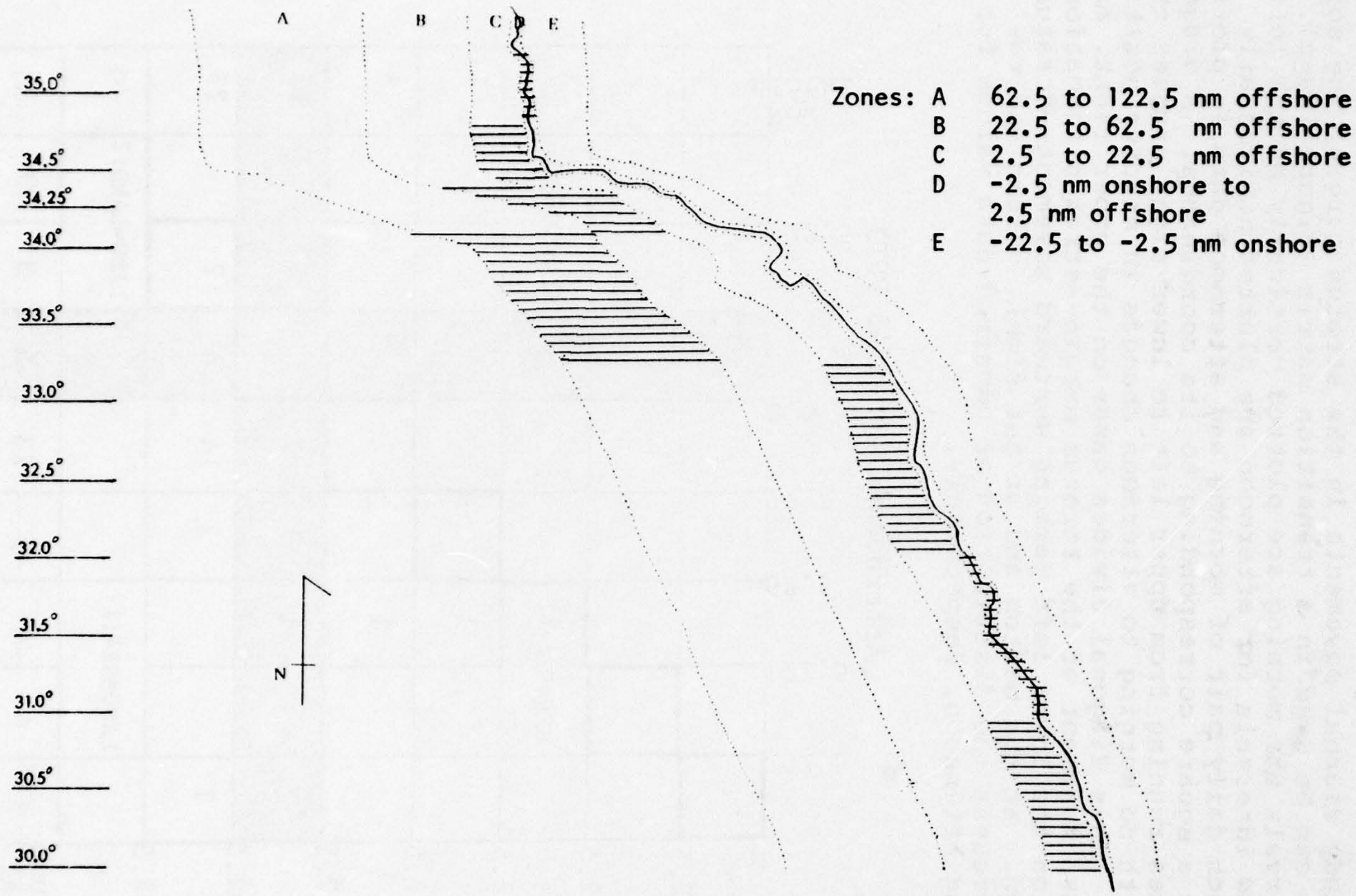


Figure 15c. Modal Stratus Frequency by Zone, Afternoon (1445-1545 PST), July 1977-1978.

Diurnal Movement

To study diurnal movements in the stratus margin, the sorting system can be used in a transition matrix (figure 16a-c). Class intervals for morning are plotted vertically on the left margin, and intervals for afternoon are plotted horizontally above. Each daily pair of morning and afternoon data is plotted by zone in a square corresponding to its coordinates. A diagonal set of boxes running from upper left to lower right crosses those squares with no morning to afternoon changes in stratus position (by zone). This diagonal divides cases on the upper right, marking eastward movement of the stratus margin--stratus formation, and those on the lower left marking westward movement--stratus dissipation. At the bottom and at the right, column and row totals represent the distribution of unpaired data values for morning and afternoon, respectively.

Afternoon (1445-1545 PST)

Morning (0745-0845 PST)	> 202.5	202.5–122.5	122.5–62.5	62.5–22.5	22.5–2.5	2.5–-2.5	-2.5–-22.5	< -22.5	Row Total
> 202.5				2					2
202.5–122.5									0
122.5–62.5		SEA⇒SEA:4					SEA⇒LAND:0		0
62.5–22.5			1						1
22.5–2.5			1		2				3
2.5–-2.5	2		1	1	7		1		12
-2.5–-22.5	1			2	14	4	2		23
< -22.5		LAND⇒SEA:17					LAND⇒LAND:2		0
Column Total	3	0	3	5	23	4	3	0	41

Figure 16a. Cloud Edge Transition Matrix at 30°N, July 1977-1978. *Afternoon cloud edge position vs morning position by zone; heavily-outlined boxes running upper left to lower right indicate cases of no morning-afternoon change by zone; shaded column and row give shoreline position; distance is in nautical miles.*

Afternoon (1445-1545 PST)

Morning (0745-0845 PST)

	>	202.5	122.5	62.5	22.5	2.5	-2.5	-22.5 <	Row Total
>	6								6
202.5	1	1	SEA⇒SEA:25						2
122.5	1	1	8		1		SEA⇒LAND:0		11
62.5			2						2
22.5		1	2	2					4
2.			3	2	2	1			8
-2.5		1	1	4	1	1	1	LAND⇒ LAND: 2	9
-22.5 <	LAND⇒SEA:8		1	1			1		3
Column Total									

Figure 16b. Cloud Edge Transition Matrix at 34°N, July 1977-1978. *Afternoon cloud edge position vs morning position by zone; heavily-outlined boxes running upper left to lower right indicate cases of no morning-afternoon change by zone; shaded column and row give shoreline position; distance is in nautical miles.*

Afternoon (1445-1545 PST)

Morning (0745-0845 PST)	> 202.5	202.5 – 122.5	122.5 – 62.5	62.5 – 22.5	22.5 – 2.5	2.5 – -2.5	-2.5 – -22.5	-22.5 <	Row Total
> 202.5	5	1							6
202.5 – 122.5			1						1
122.5 – 62.5	2			1			SEA→LAND:0		3
62.5 – 22.5	1	SEA→SEA:12							1
22.5 – 2.5					1				1
2.5 – -2.5						2			2
-2.5 – -22.5	1		2	1	5	13	7		29
-22.5 <	LAND→SEA:10				1		LAND→LAND:7		1
Column Total	9	1	3	2	7	15	7	0	44

Figure 16c. Cloud Edge Transition Matrix at 35°N, July 1977-1978. *Afternoon cloud edge position vs morning position by zone; heavily-outlined boxes running upper left to lower right indicate cases of no morning-afternoon change by zone; shaded column and row give shoreline position; distance is in nautical miles.*

Upper Wind Sorting Procedure

No offshore inversion data were available to investigate cloud patterns immediately south of the Arguello headland; SNI being considered too far to the south. In particular, the height of the inversion base south of Arguello, which is low compared to elsewhere, could not be compared with stratus margin information. But because inversion characteristics south of the Arguello headland appear to be greatly influenced by frequent northerly wind flow over the headland (Smith et al., 1964; Roberts et al., 1970), upper wind flow at Vandenberg was chosen for correlation with stratus conditions.

Upper air winds were chosen for analysis rather than surface winds, which are subject to a strong channeling effect. Thus, the first level available above the surface, 850 mb, was used. This level is high enough to be free of undue topographic influence, but still low enough to be reasonably well coupled with overall marine layer flow below (Edinger, 1960; Neiburger et al., 1945). Several groupings of the 850 mb wind flow into directional semicircles were attempted to determine if stratus at 34°N was more prevalent under certain wind flow conditions than others. Morning (0745-0845 PST cloud data; 0400 PST soundings) was chosen in order to investigate nearshore stratus behavior, which is likely to reflect topographic influence.

DATA PRESENTATION

Cloud Position at Morning, Midday, and Afternoon

Three maps (figures 13a-c), representing overall conditions at one of the three times of day, reveal distinct diurnal fluctuations in the low cloud layer. At each parallel the cloud edge dissipates away from the coast morning to midday and continues to do so midday to afternoon. Still, at 30°N, 31°N (northern Baja California), and 35°N (central California) dissipation is limited, usually occurring over small distances near the coast. On the other hand, at 32°N, 33°N, and especially 34°N (southern California) dissipation is great, frequently taking place over distances of 50 nmi or more.

At 30°N and 31°N, the morning stratus edge (figure 13a) is most frequent in a narrow zone from the shoreline inland about 15 nmi. The stratus edge does not often occur even a few nautical miles west of the coastline, and offshore clearing of 150 nmi breadth is rare, occurring on less than five percent of the observations. Inland, the penetration of the cloud layer appears to be limited by the narrowness of the coastal strip. The 600 meter contour shown in the figure marks the approximate limit of eastward penetration at about 20 nmi at both parallels.

By midday (figure 13b) relatively little seaward retreat of the stratus margin has occurred at 30°N and 31°N, and the coastal strip up to 5 nmi inland is usually still shrouded by low cloudiness. By afternoon additional dissipation occurs, but this clearing usually extends only a short distance offshore. Diurnal burnoff is also limited at 31°N so that more often than not the shoreline is still cloudy.

At 32°N the diurnal stratus regime is similar to the pattern farther south with one important exception: morning penetration of the cloud edge is nearly always limited to no more than 5 nmi

onshore. This is to be expected, for at this latitude the 600 meter contour lies between 5 and 10 nmi from shore (figure 13a). Nevertheless, despite the limited inland extent, stratus nearly always covers the immediate shoreline.

At 33°N, morning stratus often extends well inland into the coastal strip to about the position of the 600 meter contour (about 15-20 nmi inland) as shown by figure 13a. By afternoon (figure 13c) stratus is almost completely absent from land or the adjacent coastal waters. Seventy-five percent of the observations are greater than 30 nmi from shore. This pattern contrasts sharply with those found farther south where little daily westward movement of the stratus margin occurs.

At 34°N, morning stratus extends as far inland as anywhere in the study area; occurrences up to 40 nmi inland are shown. This is explained by the presence of the open, east-west aligned San Gabriel Valley that runs along this parallel extending inland about 80 nmi (figure 13a). As was the case with 33°N, diurnal dissipation of the cloud edge at this latitude is quite marked: by afternoon more than 50 percent of all occurrences appear at distances greater than 50 nmi offshore. However, figure 13a shows that even during the morning, the stratus edge often lies offshore, and significantly, these offshore occurrences form a cluster at about 80 nmi offshore. Often by midday and especially by afternoon, this clustering, while remaining at about the same position relative to the coast, grows markedly and dominates the distribution. The offshore clustering of the cloud edge is more prominent at 34.25°N than at 34°N (figure 17), and is also located closer to the coastline. Still diurnal burnoff appears to affect each of these distributions similarly: the offshore peaks grow at the expense of the morning nearshore maximums.

In contrast with the dissipation regimes discussed for latitudes 33°N and 34°N, diurnal stratus changes at 35°N are extremely limited. Morning penetration is substantial (figure 13a), often extending 20 nmi inland to about the vicinity of the 600 meter contour. Midday and afternoon clearing is slight (figures 13b-c), with very little dissipation of the cloud edge farther west than 10 nmi offshore by afternoon. As in Baja California, the afternoon stratus often shrouds the shoreline. Still, the percentage of occurrences farther than 150 nmi offshore is far greater at 35°N than along the Baja California coast at all times of day, indicating a greater prevalence of stratus-free weather over the coastal waters in south central California.

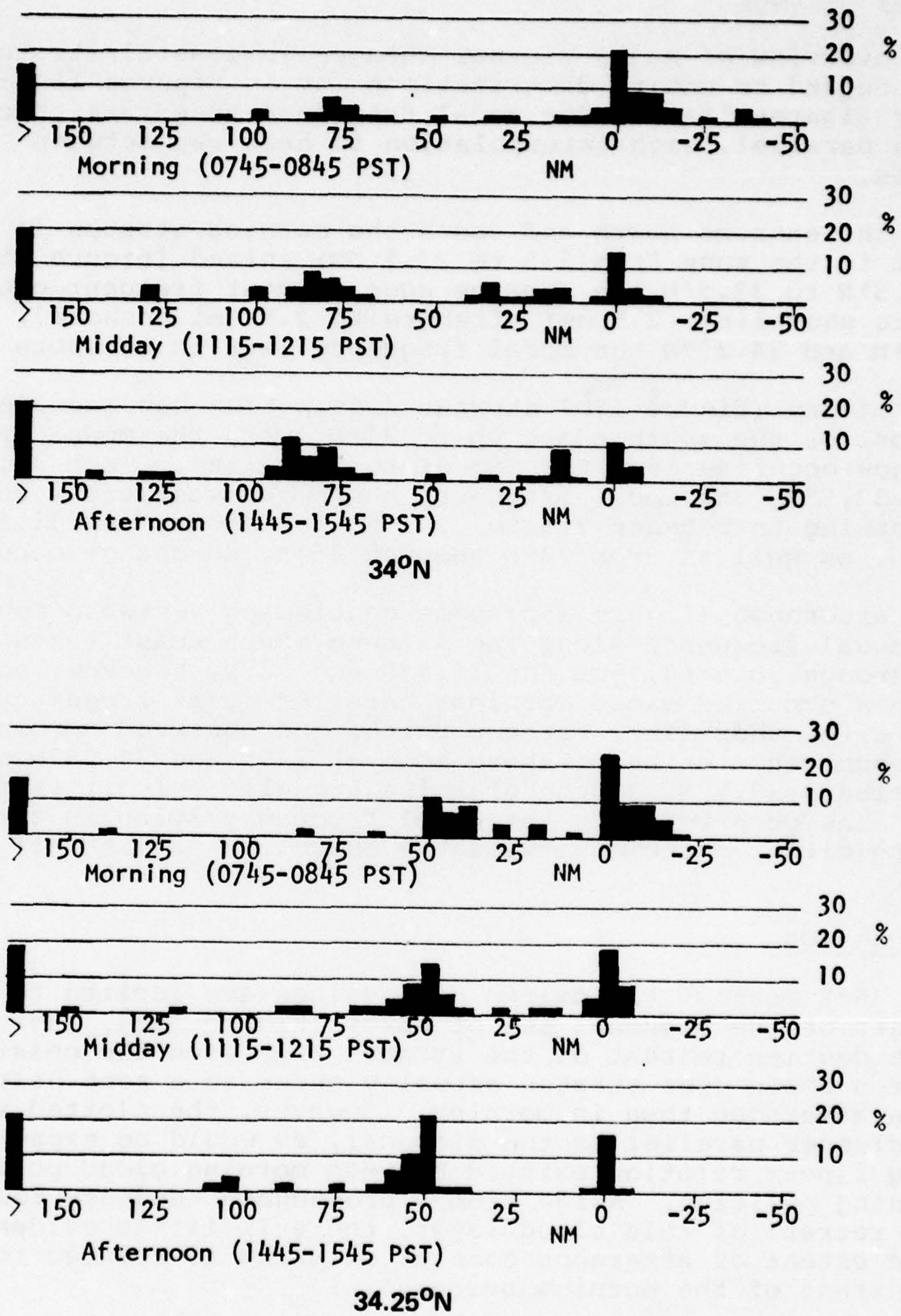


Figure 17. Stratus Margin Cross-Sections for 34°N and 34.25°N, July 1977-1978.

Frequency by Zone

An overview of major diurnal changes in coastal stratus, without regard to entire distributions (as in figures 13a-c), is given by figures 15a-c. The modal frequency zones are hatched for each parallel, with interpolation to half way between parallels.

In the extreme north and south the morning stratus is most frequent in the zone from 2.5 to 22.5 nmi inland (figure 15a). From 31.5°N to 33.5°N the stratus edge is most frequent over the immediate shoreline (2.5 nmi offshore to 2.5 nmi onshore). At both 34°N and 34.25°N the modal frequency lies in offshore zones.

At midday (figure 15b) stratus dissipation has occurred along most of the south coast up to 31°N, with the modal frequency now occuring over the immediate shoreline. From 32.5°N through 33.5°N, the modal frequency has moved westward a zone since morning to between 2.5 to 22.5 nmi offshore. At 31.5°N and 32°N, as well as from 34°N through 35°N, no change occurs.

By afternoon (figure 15c) some continuing westward movement of the modal frequency along the extreme south coast takes place (30°N through 30.5°N), but for 31.5°N and 32°N, however, no change has occurred since morning; here the modal frequency still lies over the shoreline. Farther north, the observed morning and midday occurrence of an offshore mode at 34°N and 34.25°N now also includes 33.5°N. North of Point Arguello only limited dissipation has occurred with the modal frequency lying in zones which are either coincident with the shoreline or just slightly offshore.

Diurnal Motions

At 30°N most of the paired data values are located to the lower left of the diagonal set of boxes (figure 16a), indicating frequent daytime retreat of the stratus away from the coast. In only three cases does stratus actually occur in a zone nearer to shore in afternoon than in morning. However, the plotted values do not cluster parallel to the diagonal, as would be expected if a strong linear relation existed between morning cloud position and evening position. Aside from a pronounced tendency toward diurnal retreat of this cloud layer, there is little evidence that the extent of afternoon coastal clearing is related to the inland extent of the morning overcast.

About one-third of all the data is concentrated in the box depicting a morning position of 2.5 to 22.5 nmi inland, and an afternoon position of 2.5 to 22.5 nmi offshore. In this situation the stratus recedes a slight distance seaward after covering

a narrow potion of the coastal land areas. Moreover, the remaining values are clustered in nearby boxes, indicating that the eastern edge of the cloud layer often fluctuates within narrow nearshore limits diurnally, frequently crossing the shoreline in the process.

At 34°N (figure 16b) the range of diurnal paths of the stratus edge is greater than at 30°N (figure 16a). The only concentration of data values occurs in the box indicating a cloud position in an offshore zone (between 62.5 and 122.5 nmi offshore), for both morning and afternoon. This zone roughly separates the nearshore waters inside the southern California bight to the east from the open sea to the west.

Two distinct patterns of dissipation take place within these two divisions. If the morning cloud edge occurs from 62.5 nmi, from shore out to sea, the position of the afternoon cloud edge appears to be directly related (as evidence by data values, which lie close and parallel to the diagonal set of boxes). However, if the morning cloud edge lies closer to shore than 62.5 nmi, the afternoon burnoff position appears unrelated. In other words, the nearshore region has a strong tendency for pronounced seaward retreat of the stratus, but the afternoon extent of this retreat seems to be about as great regardless of the morning cloud edge position.

Figure 16c shows that at 35°N the paths of diurnal dissipation are fewer than at 34°N. Only 15 boxes contain at least one case, compared to 24 cases at 34°N, indicating less diurnal variability of stratus there.

<u>Discussion</u>

The preceding graphical representations revealed some important trends:

1. Stratus frequently extends over the land areas especially in morning, but its inland penetration varies greatly depending on the presence of mountainous terrain;

2. Stratus often remains near the shoreline and exhibits little diurnal variability south of about 33°N and north of about 34.5°N; between these two limits the location of the stratus is more variable and diurnal dissipation is more pronounced;

3. A strong tendency exists for extensive morning onshore stratus to burn off at least to the coastline;

4. A sharp discontinuity often occurs between clearing to the east and dense cloud cover to the west in the vicinity of Point Arguello and southward to about 33°N.

The general results presented here agree well with Navy ship report data (Naval Weather Service, 1971) and Simon (1977) for the region in the southern California bight than farther north and south; also, both indicate a frequent distinct boundary between offshore overcast and nearshore clearing south of Point Arguello. Simon also finds more diurnal dissipation of stratus in the southern California bight than elsewhere.

REDUCED STRATUS OFF SOUTHERN CALIFORNIA

Results of the previous section, sectorized ship report data, and limited offshore inversion information all suggest that just south of the Arguello headland the stratus boundary often coincides with a sharply sloping inversion base. Also, a stratus boundary here is not likely to coincide with a strong mean gradient in sea surface temperature.

Inversion Base Height

Comparison of ceiling data for July (figure 5) with averaged inversion height data (figure 2), indicates a pronounced area of low inversions and infrequent ceilings just south of the Arguello headland (34.25°N). Southward to about the latitude of Los Angeles (34°N), both the average inversion height and the incidence of ceilings rise rapidly. Cloud edge data (figures 13-17) also indicate an area of frequent clearing in the region of low inversion height. This clearing is more pronounced just south of the Arguello headland, where the inversion height is the lowest, than off Los Angeles (figure 17). Although these correlations are striking, the period of available averaged inversion height data for the offshore region (figure 2) spans only a short period (August-September of 1966), and covers a limited portion of the coastal waters. In particular, south and west of Point Arguello, no average information is available.

The August 22, 1966 inversion characteristics near Point Arguello (figure 3) represent data for only one day, but according to Roberts et al. (1970) provide a representative example. In this regard, it fits well with the averaged information of Edinger and Wurtele (1971) in figure 2. The sharp westward increase in inversion height just south of Point Arguello corresponds to the position of the offshore maximum in stratus margin frequency at 34.25°N, located about 50 nmi from shore (figure 17).

The hypothesis that the offshore stratus boundary is accompanied by a pronounced slope in inversion height south of the area near Point Arguello is probably valid but is difficult to

document due to a lack of data. A mean trough in inversion base height that probably lies off southern California (Neiburger et al., 1945) does exhibit increasing depth in the same vicinity as the usual cloud boundary. Although based only on island and mainland soundings, the location of such a trough would support a relation between the offshore cloud edge and increased inversion base height.

Sea Surface Temperature

If advection of stratus over warm waters strongly promotes dissipation, clouded regions would end over or just downwind of a strong positive gradient in temperature. Sea surface temperature information for July (figure 1) and cloud edge data (figures 13a-c) reveal that this is roughly the case in the vicinity of 33°N, especially in midday and afternoon. Still, such a correlation is not evident at 34°N. Pronounced clustering of cloud boundaries occurs upwind (to the west) of the strongest sea surface temperature gradient at all times of day (figures 13 and 17). In fact, over the region of strongest gradient in sea surface temperature, (about 40-70 nmi offshore) the cloud edge is usually absent. This analysis does not suggest that mean sea surface temperatures are unimportant in explaining low cloudiness patterns, but that they do not explain a sharp discontinuity in cloud coverage often present just south of Point Arguello.

Subsidence and Stratus Dissipation

The lowered inversion base and decreased cloudiness in the southern California bight would seem to be related to lee waves, induced by prevailing northwesterly flow as it crosses the Arguello headland. Subsidence, in addition to that already present associated with the Pacific anticyclone, would warm the affected air and reduce the marine layer height to below the condensation level. Accompanying turbulence could dilute the moist layer with dryer inversion air. The offshore cloud boundary would mark the westward limit of these processes. The effect should be strongest just south of the Arguello headland and diminish southward. At some distance away from the headland the effect would no longer exist, and low cloud cover and marine layer depth would return to normal.

The findings both by Neiburger et al. (1945) and Edinger and Wurtele (1971), of anomalous moisture above the inversion base support this explanation. This moist inversion air could still be of marine layer origin, but warmed by strong subsidence in the lee of the Arguello headland to the north. Moreover, the marine layer in the Santa Barbara Channel is topped by a moist inversion more often than off Los Angeles, according to Edinger and Wurtele. This difference suggests that subsidence is more pronounced near the headland than farther downstream.

Sorting Procedure Results

Cloud edge data for 33.5°N through 34.5°N (figures 13-17) indicate that south of Point Arguello the cloud boundary frequently remains well offshore, but sometimes extends to the shoreline. At 34.25°N (figure 17) the bimodal distribution suggests that the boundary lies in one position or the other but not often in between. Significantly, the inversion minimum, which seems to be related to decreased cloudiness in the region, sometimes is not present (Edinger and Wurtele, 1971).

Because cloud and inversion characteristics seem to be related to prevailing wind flow, Vandenberg 850 mb flow was analyzed (as outlined in Section 3), to determine favorable stratus conditions. Of the different experimental groupings of the 850 mb wind direction at Vandenberg, one gave substantially more interesting results. When the wind blew from 340° to 159° (hereafter referred to as the "northeast group"), morning stratus at 34°N was much less prevalent than when it blew from 160° to 339° ("southwest group"). To illustrate this, figure 18 gives the distribution of the cloud edge by sorting zone for both directional semicircles. Referenced by the northeast group, stratus is less frequent onshore and more frequent well offshore than for the southwest group. A sharp maximum appears in the northeast group at between 62.5 and 122.5 nmi offshore, corresponding to a position just south of Point Arguello. No such maximum appears in the southwest group. However, the southwest group shows a strong maximum between 2.5 and 22.5 nmi inland, which the northeast group does not.

The difference in the two sets of data is also shown by their medians. In the southwest group the median lies just at zero (right over the coastline). In the northeast group the median lies well offshore at 32 nmi. This difference does not occur at 35°N, just north of Point Arguello. At the latter latitude, the two sets of cloud edge positions referenced by wind direction were found to be not markedly different from one another. In fact, the median of the northeast group lies slightly more onshore than the median of the southwest group (-2 nmi compared to -6 nmi).

In figure 19 the morning modal frequency zones for parallels 33.5°N through 35°N are plotted, similarly to figures 13a-c, but referenced by the two wind direction groups. Identical patterns exist for both groups at 34.5°N and 35°N, but south of the Arguello headland a pronounced difference appears. The zonal modes occur offshore at 34°N and 34.25°N referenced by the northeast group, but onshore referenced by the southwest group. South of 33.5°N there is little difference between the groups (not shown in the figure).

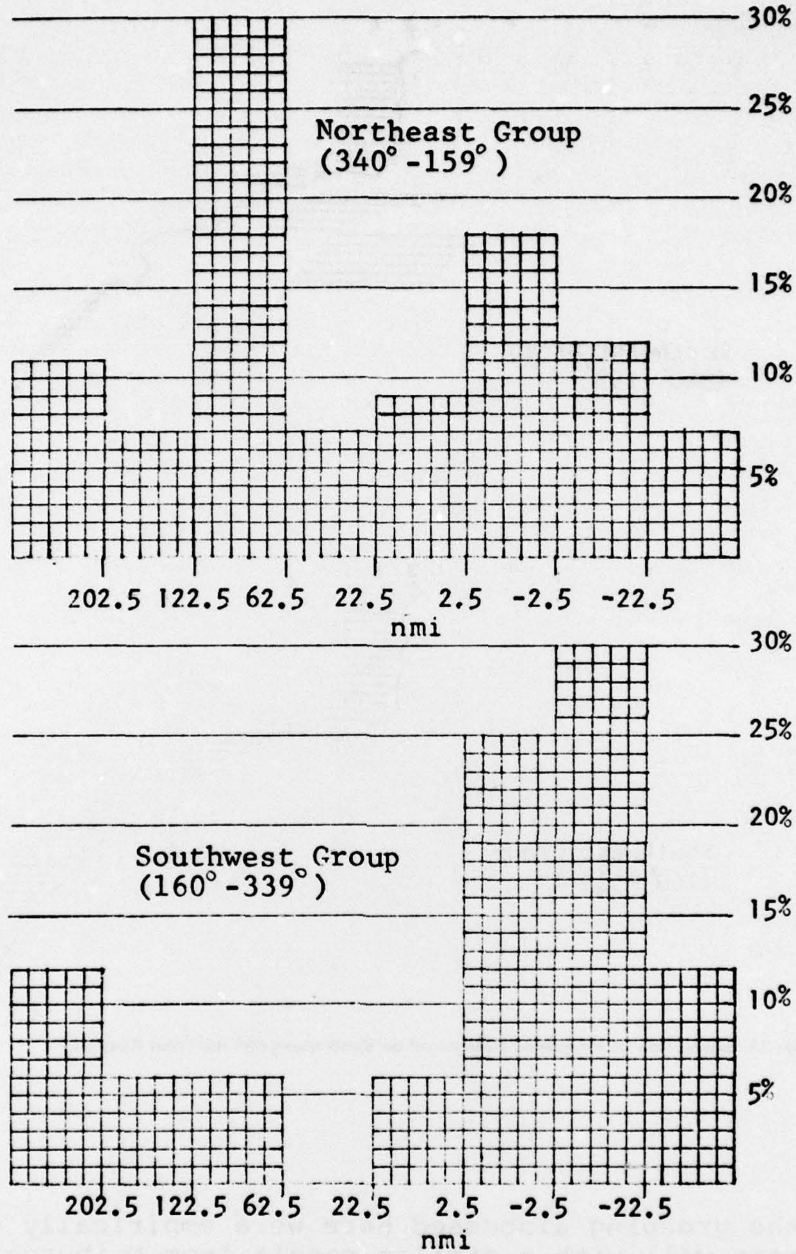


Figure 18. Stratus Frequency Zone at 34°N. *Referenced by Vandenberg 850 mb Wind Direction. Morning (0745-0845 PST cloud data, 0400 PST winds).*

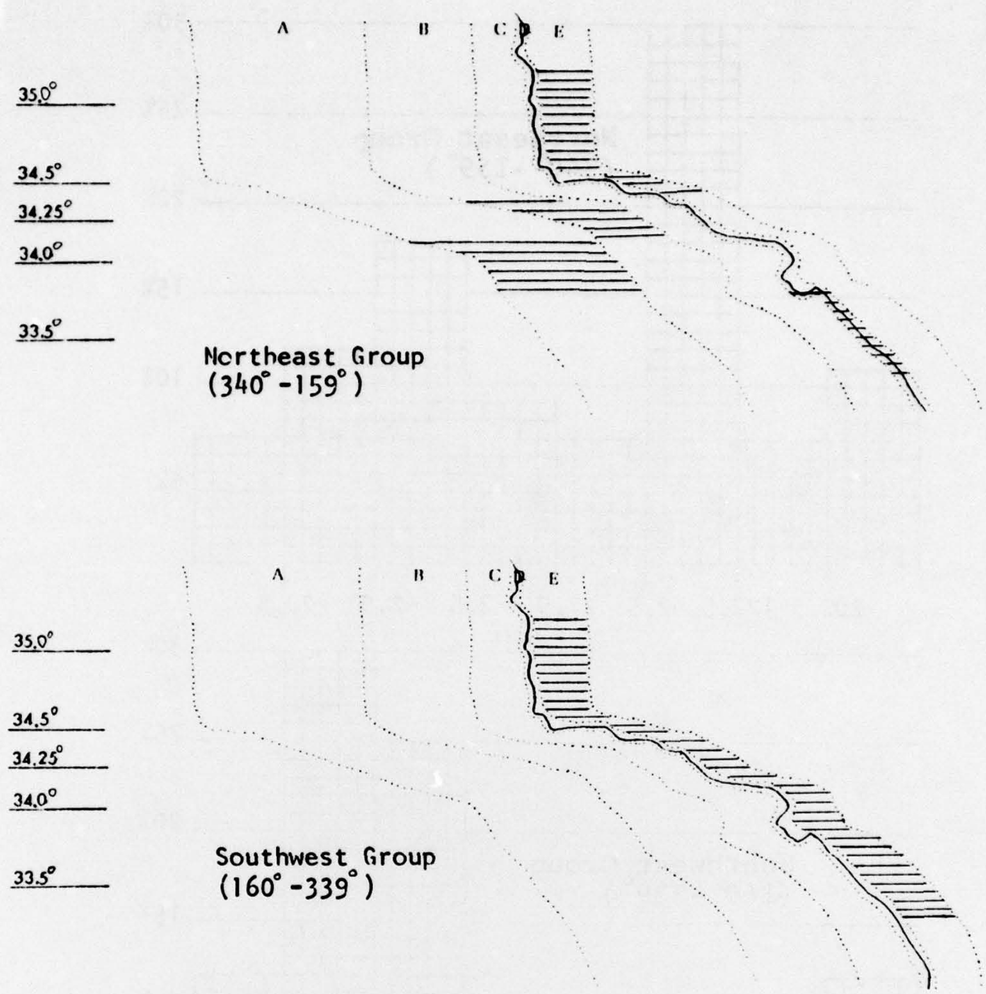


Figure 19. Modal Stratus Frequency Referenced by Vandenberg 850 mb Wind Direction.

Discussion

Though the grouping discussed here were empirically determined, it agrees well with a similar result from Neiburger et al. (1945). The finding here strengthens the hypothesis that frequent lee subsidence over the Arguello headland induces clearing to the south. The magnitude of this effect seems to diminish gradually southeast of the headland, but probably rapidly to the southwest, out of the wind shadow of the headland.

The large disparity between the two wind direction groups probably results from a channeling mechanism around Point Arguello. Channeling into the bight would likely occur in conjuction with

the southwest group but not with the northeast group. Helvey's (1970) findings suggest that a sharp division between channeling and sheltering exists at a north-northwest Vandenberg 850 mb direction. This agrees well with the break point in the sorting procedure used here--340°.

In more southerly reference wind flow, unmodified marine flow, probably associated with stratus, could easily extend to the southern California coastline. But in more northerly wind flow, only modified marine air could reach the bight. Stagnant air flow would prevail, associated with increased subsidence and reduced stratus. The size of the downstream area affected by sheltering would vary depending on the trajectory of the prevailing flow.

North of Point Arguello at 35°N this effect is not apparent (figure 19). Convergence of the prevailing flow windward of the Arguello headland (as modeled by figure 4) probably deepens the marine layer here. Heavy onshore morning stratus shown in figure 13a provides evidence of this effect.

In a few cases, northerly Vandenberg 850 mb flow was associated with heavy coastal cloudiness and no clear region south of Point Arguello. These events, which represent exceptions from the general trend, probably were associated with strong Catalina eddys. Strong cyclonic curvature in the 850 mb wind field south of Vandenberg, as might be expected during a well-developed Catalina eddy, would explain such deviations. Such mesoscale information is unavailable. In general, however, Catalina eddys seemed to occur in conjunction with southwest group flow.

Some Reasons for Enhanced Diurnal Stratus Dissipation off Southern California

It has been shown that stratus off southern California appears to dissipate over greater distances than elsewhere. Satellite pictures show that morning stratus within the bight is also often thinner than farther offshore (Rosenthal, 1977), possibly from the sheltering effect already discussed. Thus, dissipation processes of relatively small magnitude could clear the bight under these circumstances.

Fluctuations in marine layer depth is one of the most important processes by which dissipation of stratus occurs. Afternoon falls in marine layer depth appear to be greatest at the mouths of deep coastal valleys, as the sea breeze diverges into these valleys (Edinger and Wurtele, 1971). Because the coastal plain is extensive between 34.5°N and 33°N (figure 13a), generally large afternoon height falls in the marine layer offshore would be expected. This in turn would lead to rapid seaward burnoff of low cloudiness.

Forecasting Implications

Use of pressure gradients between the coast and desert to forecast stratus was suggested by Neiburger et al. (1945), and is widely practiced by California meteorologists at the present time. In addition, the trajectory of marine layer flow should receive closer attention. Small wind shifts around the prevailing wind direction can make a large difference in stratus cloud cover amounts near land inside the southern California bight. In particular, the sheltering effect of the Arguello headland can protect the southern California bight and coastal land areas, even when strong northwest winds prevail overall. In such a situation, indicative of a strong pressure gradient, the coastal areas north of Point Arguello and south of San Diego are subject to strong onshore flow and heavy stratus.

The sorting procedure used in this analysis demonstrates the utility of GOES satellite imagery in predicting approaching weather changes. For example, the area of clearing often present just south of the Arguello headland varies in size, in apparent dependence on the magnitude of lee subsidence. Filling in of this "hole" on successive pictures would likely indicate development of vigorous, low level southerly flow, perhaps associated with a strengthening Catalina eddy. On the other hand, appearance of this hole after a period of solid overcast in the southern California bight would indicate strengthening northwesterly flow. In such an instance the bight might be expected to clear owing to increasing forced subsidence over the area.

The latitudinally-dependent diurnal dissipation of low clouds along the United States west coast as determined by statistics compiled from GOES imagery constitutes in itself an important predictive tool. Quantitative estimates can now be made of the extent and time at which low clouds will dissipate over portions of the Southern California Operating (SOCAL) Areas, for Fleet and other Navy operations. The presence of coastal stratus along the west coast of South America and Africa, pose the interesting possibility that those regions too are subject to predictive processes of diurnal formation and dissipation. GOES imagery appears to be the only available method for investigating such processes in these areas as well.

CONCLUSION

With the advances in satellite technology has come great improvement in understanding stratus off the west coast of continents at subtropical latitudes. In particular, geostationary systems can follow intricate changes in cloud behavior over periods of just a few hours, resulting in short-period quantitative forecast guidance.

BIBLIOGRAPHY

Byers, H.R., 1930. "Summer Sea Fogs of the Central California Coast." University of California Publications in Geography, Vol. 3, pp. 291-338.

Demarrais, G., G. Holzworth, and C. Hosler, 1965. "Meteorological Summaries Pertinent to Atmospheric Transport and Dispersion over Southern California." Technical Paper No. 54, U.S. Weather Bureau, Washington D.C.

deViolini, Robert, 1974. Climatic Summary for the Pacific Missile Test Center, Point Mugu, Calif., Geophysics Division, Pacific Missile Test Center Technical Publication TP-75-25.

Dvorak, V.F., 1966. An Investigation on the Inversion-Cloud Regime over the Subtropical Waters West of California. M.S. Thesis, University of California at Los Angeles.

Edinger, James G., 1960. The Influence of Terrain and Thermal Stratification on Flow across the California Coastline. University of California at Los Angeles, Sponsored by Geophysics Research Directorage of the Air Force Cambridge Research Center, Air Research and Development Command, Contract No. AF 19(604)-5212.

Edinger, J.G., and M.G. Wurtele, 1971. Marine Layer over Sea Test Range. Report prepared by University of California at Los Angeles for Pacific Missile Range, Technical Publication PMR-TP-71-2, Contract N123(61756)56992A.

Edinger, J.G., and M.G. Wurtele, 1972. "Interpretation of some Phenomena observed in Southern California Stratus." Monthly Weather Review, Vol. 100, No. 5, pp. 389-398.

Gerst, Anthony Leo, 1969. Correlation of Sea Surface Temperatures with Cloud Patterns off the West Coast of North America during the Upwelling Season. Thesis, Naval Postgraduate School, Monterey, Calif., 124 pp.

Helvey, R.A., 1970. "Diurnal Wind Behavior as a Function of Wind Direction and Speed at Vandenberg/Point Arguello/Santa Maria." Atmospheric Sciences Technical Note No. 25, Pacific Missile Range, Point Mugu, Calif.

Lea, D.A., 1968. "Some Climatological Aspects of the Stratus Season at Point Mugu." Atmospheric Sciences Technical Note No. 12, Pacific Missile Range, Point Mugu, Calif.

Lilly, Douglas K., 1968. "Models of Cloud-Topped Mixed Layers under a Strong Inversion." Quarterly Journal of the Royal Meteorological Society, Vol. 94, No. 401, pp. 292-309.

Naval Weather Service, 1971. Climatological Study-Southern California Operating Area. Fleet Weather Facility, San Diego, Calif.

Neiburger, Morris, 1944. "Temperature Changes during Formation and Dissipation of West Coast Stratus." Research Paper No. 19, U.S. Department of Commerce, Washington, D.C., 26 pp.

Neiburger, Morris, Charles G.P. Beer, and Luna B. Leopold, 1945. The California Stratus Investigation of 1944. U.S. Department of Commerce, Washington, D.C., 84 pp.

Petterssen, Sverre, 1938. "On the Causes and Forecasting of the California Fog." Bulletin of the American Meteorological Society, Vol. 19, No. 2, pp. 49-55.

Roberts, J.A., K.M. Beesmer, E.L. Seeman, and M.F. Harris, 1970. A Coastal Mesoclimatology of the Point Conception to Morro Bay Region of California. Report prepared for United States Army, Contract No. DAHC04 68 C0036, by James A. Roberts Associates, Inc. Tustin, Calif.

Rosenthal, J., 1965. Observed Inversion Fluctuations on the Synoptic Scale. Presented at 239th National Meeting of American Meteorological Society with the Pacific Division, American Association for the Advancement of Science, Riverside, Calif., 21-25 June 1965.

Rosenthal, J. and D.S. Posson, 1977. Applications of Satellite Imagery to Test and Evaluation: Progress Report. Block Program ZF52-551-001, Pacific Missile Test Center Technical Publication TP-78-04, Point Mugu, Calif.

Simon, Richard L., 1977. "The Summertime Stratus over the Offshore Waters of California." Monthly Weather Review, Vol. 105, No. 10, pp. 1310-1314.

Schroeder, Mark J., Michael A. Fosberg, Owen P. Cramer, and Clyde A. O'Dell, 1967. "Marine Air Invasion of the Pacific Coast: A Problem Analysis." Bulletin of the American Meteorological Society, Vol. 48, No. 11, pp. 573-589.

Smith, T.B., E.K. Kauper, S. Berman, and F. Vukovich, 1964. Micrometeorological Investigation of Naval Missile Facility Point Arguello, California Volume 1-Analysis. Prepared for United States Navy, Contract N123-(61756)32885A(PMR) by Meteorological Research Inc., Altadena, Calif.

U.S. Department of Commerce, 1962. Climatography of the United States No. 82-4--Summary of Hourly Observations. Los Angeles Airport and San Diego Lindbergh Field, National Oceanic and Atmospheric Administration, Asheville, N.C.

U.S. Department of Commerce, 1977a. Climatography of the United States No. 60--Climate of California. National Oceanic and Atmospheric Administration, Asheville, N.C.

U.S. Department of Commerce, 1977b. Local Climatological Data. Los Angeles International Airport and San Diego Lindbergh Field, July 1977, National Oceanic and Atmospheric Administration, Asheville, N.C.

U.S. Department of Commerce, 1978. Local Climatological Data. Los Angeles International Airport and San Diego Lindberg Field, July 1978, National Oceanic and Atmospheric Administration, Asheville, N.C.

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